POLYTECHNIQUE MONTRÉAL
UNIVERSITÉ D'INGÉNIERIE

Advances in Antenna Systems for Future Wireless Terminals

University of Central Florida (UCF)

IEEE MTT/AP Orlando Chapter

Raj Mittra Distinguished Lecture Program

Invited Talk - 14 Nov. 2019

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Short Biography

Mohammad S. Sharawi is a Professor of Electrical Engineering at Polytechnique Montréal, Montréal, Québec, Canada. He was with King Fahd University of Petroleum and Minerals (KFUPM), Saudi Arabia, between 2009-2018. He founded and directed the Antennas and Microwave Structure Design Laboratory (AMSDL) at KFUPM. He was a visiting Professor at the Intelligent Radio (iRadio) Laboratory, Electrical Engineering Department, University of Calgary, Alberta, Canada, during the Summer-Fall of 2014. He was a visiting research Professor at Oakland University during the summer of 2013.

Prof. Sharawi's areas of research include Multiband Printed Multiple-Input-Multiple-Output (MIMO) Antenna systems, Reconfigurable and Active integrated Antennas, Applied Electromagnetics, Millimeter-wave MIMO antennas and Integrated 4G/5G antennas for wireless handsets and access points. He has more than 300 papers published in refereed journals and international conferences, 9 book chapters, one single authored book entitled "*Printed MIMO Antenna Engineering*," Artech House, 2014, and the lead author of the recent book "*Design and Applications of Active Integrated Antennas*," Artech house, 2018. He has 19 issued and 15 pending patents in the US Patent Office. He is serving as the Associate Editor for the IEEE Antennas and Wireless Propagation Letters (AWPL), IET Microwaves, Antennas and Propagation (MAP), as well as Wiley Microwave and Optical Technology Letters (MOP). He served on the Technical and organizational program committees of several international conferences such as EuCAP, APS, IMWS-5G, APCAP, iWAT among many others.

Index terms:

Antennas, MIMO, 5G, Connected Arrays, Integrated Antennas, Active Antenna Systems, Correlation

Presentation Scope

- Major Research Activities (@Polytechnique Montréal)
- Technology Trends for future Wireless Systems
- 5G technologies for Antenna Systems
  - MIMO / massive-MIMO
  - Mm-waves
- Advances in Antenna systems for 5G
  - Reconfigurable antennas for cellular and Cognitive Radio (CR) platforms
  - Active Integrated Antennas
  - Use of mm-wave antenna systems
  - CAA based integrated antennas
  - Massive-MIMO Antenna systems
  - Other 5G applications
- Future Challenges

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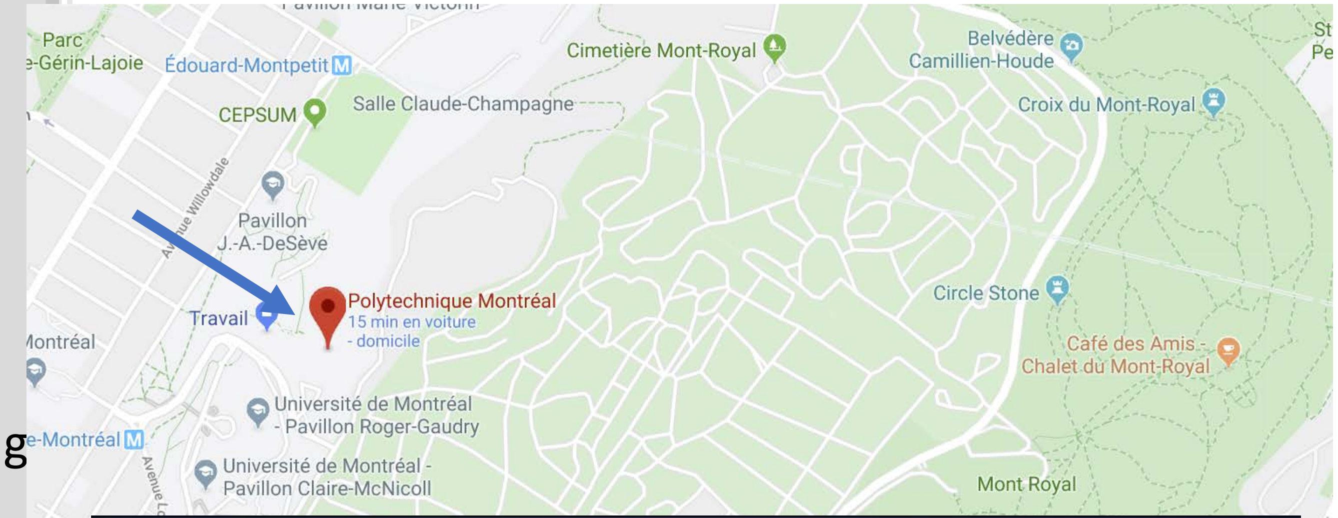
Polytechnique Montréal

- **Founded in 1873**
- **The university of Montréal Engineering School**
- Polytechnique Montréal is one of Canada's leading **engineering education** and research institutions.
- It is **Québec's largest engineering university** in terms of graduate student body size, and because of the scope of its research activities.
- **7 engineering departments** with ~8,000 students
- More than 700 students in Electrical Engineering
- Around ~150 graduate students in EE


Édouard-Montpetit
CEPSUM
Salle Claude-Champagne
Cimetière Mont-Royal
Belvédère Camillien-Houde
Croix du Mont-Royal
Avenue Willowdale
Pavillon J.-A.-DeSève
Travail
Polytechnique Montréal
15 min en voiture - domicile
Circle Stone
Café des Amis - Chalet du Mont-Royal
Université de Montréal - Pavillon Roger-Gaudry
Université de Montréal - Pavillon Claire-McNicoll
Mont Royal

POLYTECHNIQUE MONTRÉAL
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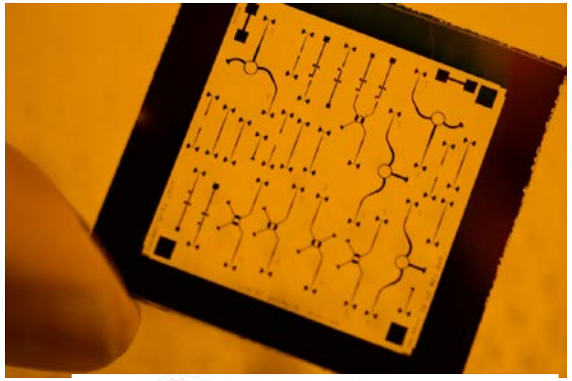
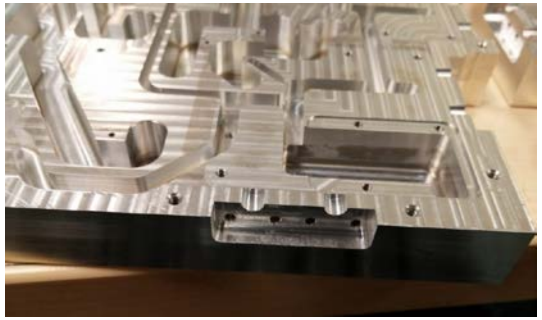
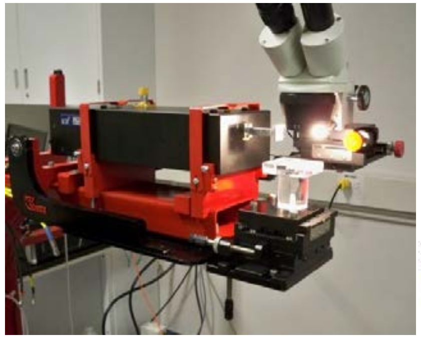
Poly-Grames Capabilities



- Multi-layer Laser based PCB fabrication (multi-layers) and MMIC
- Measurement capabilities of S-parameters up to 1000 GHZ and radiation patterns up to 500 GHz (custom setups), chamber already exists for 110GHz pattern measurements
- All CAD tools
- Among the largest research centers with more than 25 Million in equipment and resources
- Will acquire a New **RC in Dec. 2019**. Grant secured by **Prof. M. Sharawi to conduct 8x8 MIMO at sub-6GHz and 2x2 MIMO at mm-waves**. The ONLY one in an academic institution in Canada!
- Class 100 Clean Room
- More than 50 Graduate students …





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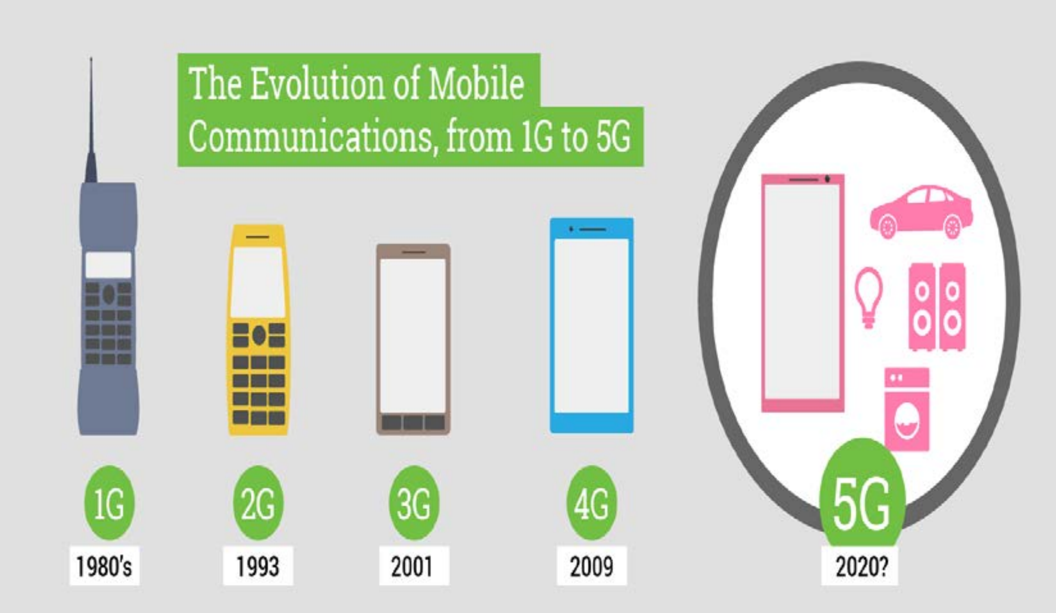
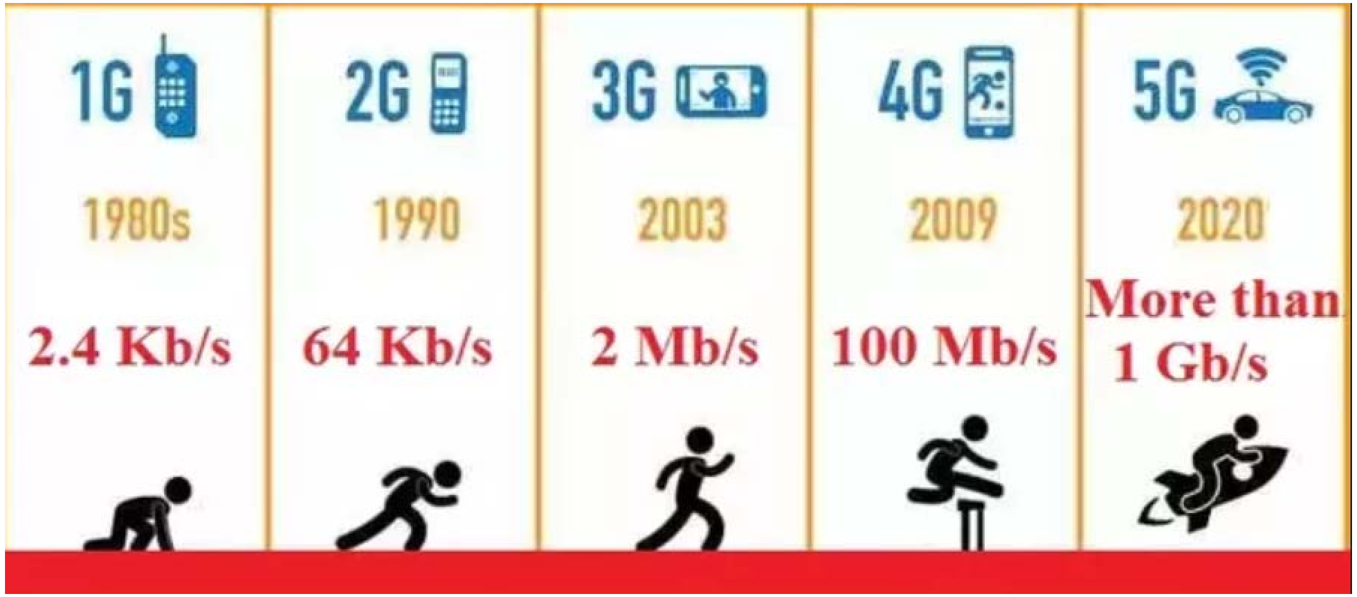
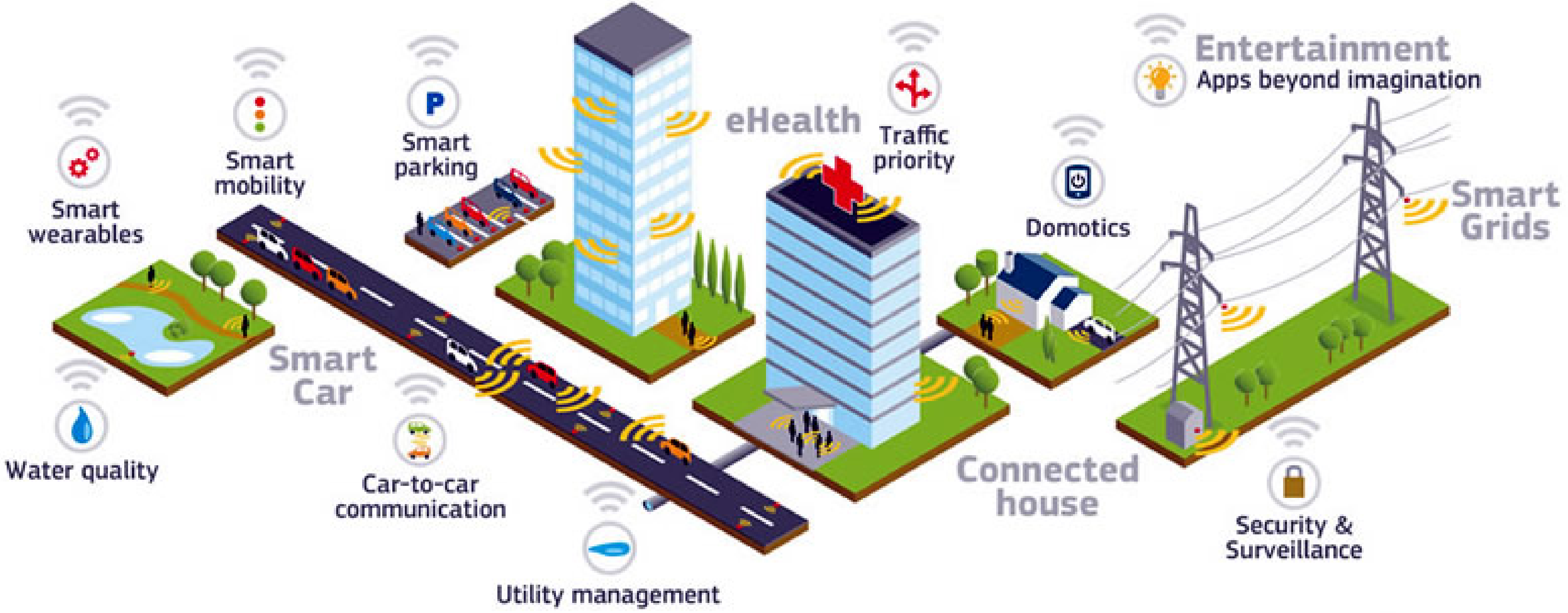
Technology Trends

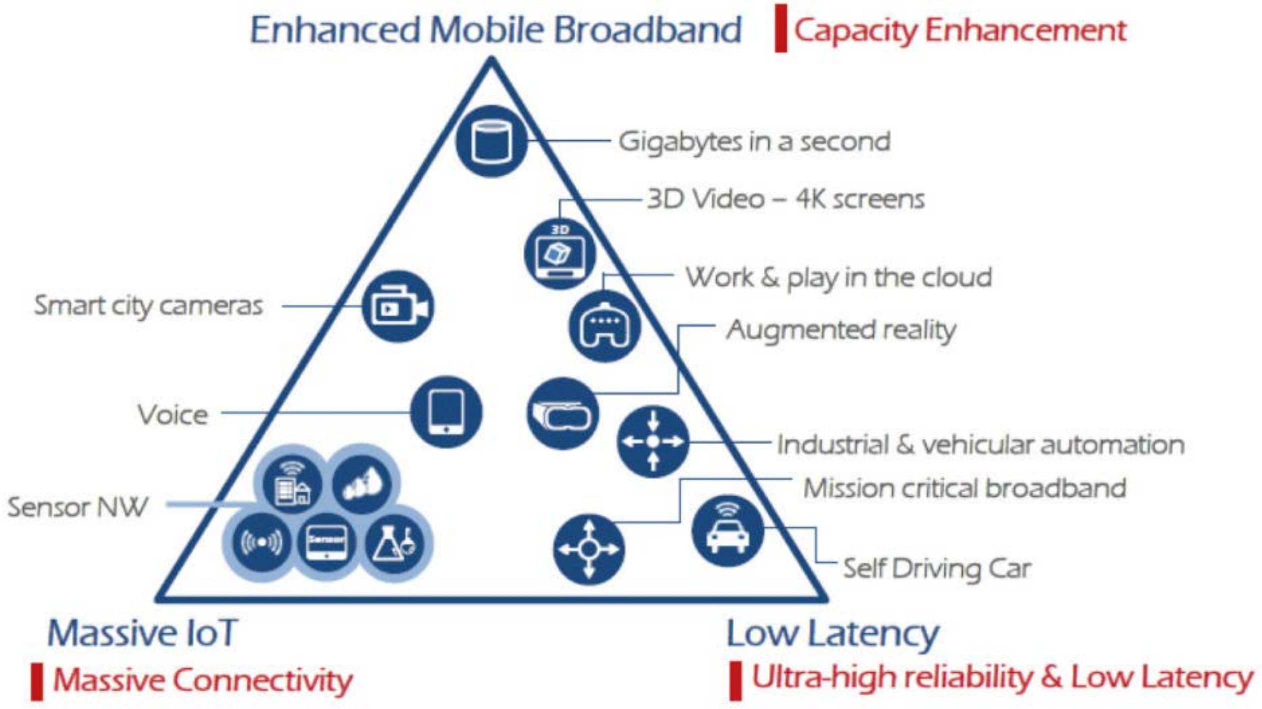

The Evolution of Mobile Communications, from 1G to 5G
1G
1980's
2G
1993
3G
2001
4G
2009
5G
2020?


1G
1980s
2.4 Kb/s
2G
1990
64 Kb/s
3G
2003
2 Mb/s
4G
2009
100 Mb/s
5G
2020
More than 1 Gb/s

- **Approximately every decade a new standard for mobile communications evolve to satisfy speed and reliability needs**
- **4G at present is serving well but the requirements for higher speeds and other emerging applications cannot be met with 4G**
- **The initial promise of 5G is its incredible speed, 100-1000 times faster than 4G.**


Smart wearables
Smart mobility
Smart parking
eHealth
Traffic priority
Entertainment
Apps beyond imagination
Domotics
Smart Grids
Smart Car
Water quality
Car-to-car communication
Connected house
Security & Surveillance
Utility management

5G standard will be the first to bring together not only smartphones and tablets but also connected objects from household equipment, moving vehicles, Wearable on body sensors, the concept of IoT and its massive deployable Sensors, etc.



Enhanced Mobile Broadband | Capacity Enhancement

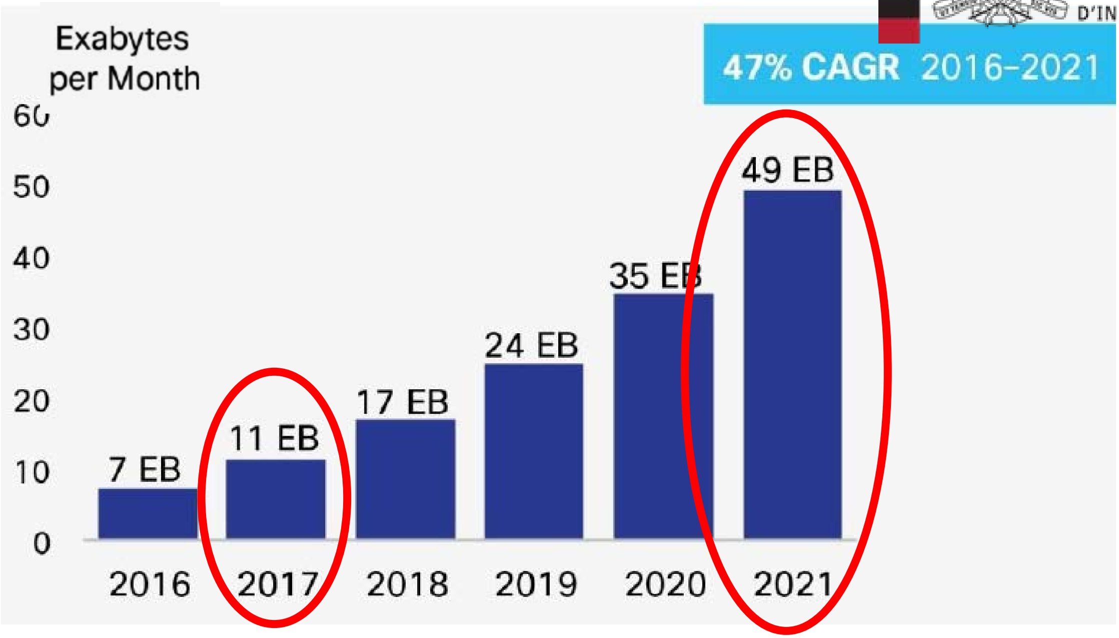
Gigabytes in a second
3D Video – 4K screens
Work & play in the cloud
Augmented reality
Industrial & vehicular automation
Mission critical broadband
Self Driving Car
Smart city cameras
Voice
Sensor NW

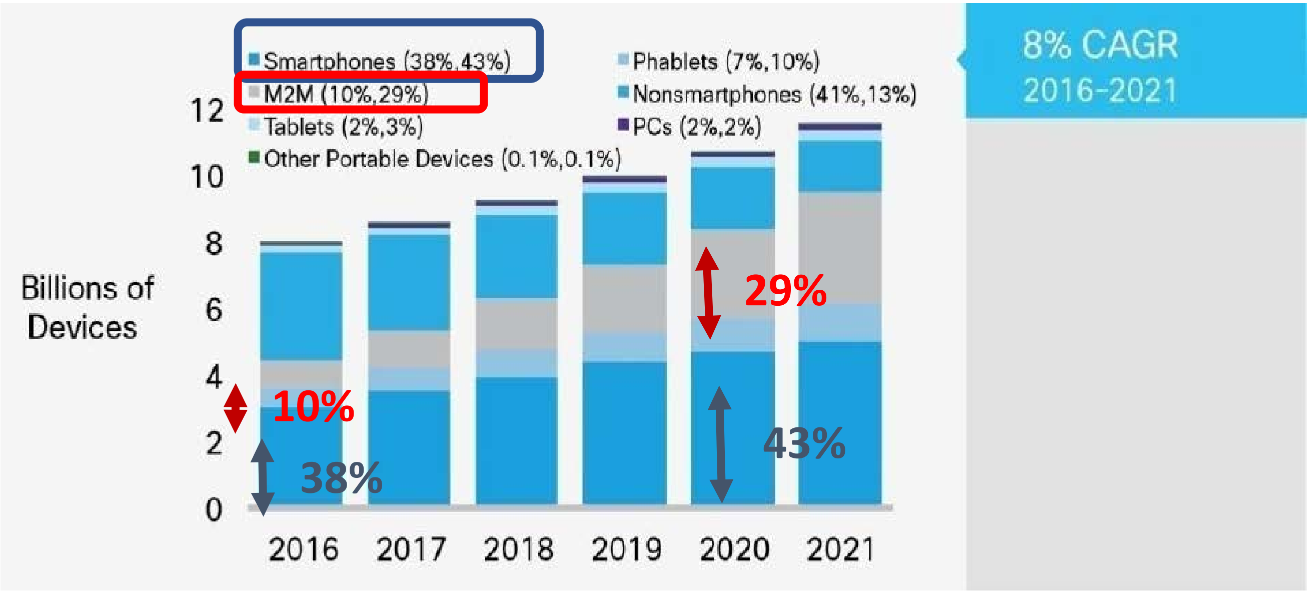
Massive IoT | Massive Connectivity

Low Latency | Ultra-high reliability & Low Latency

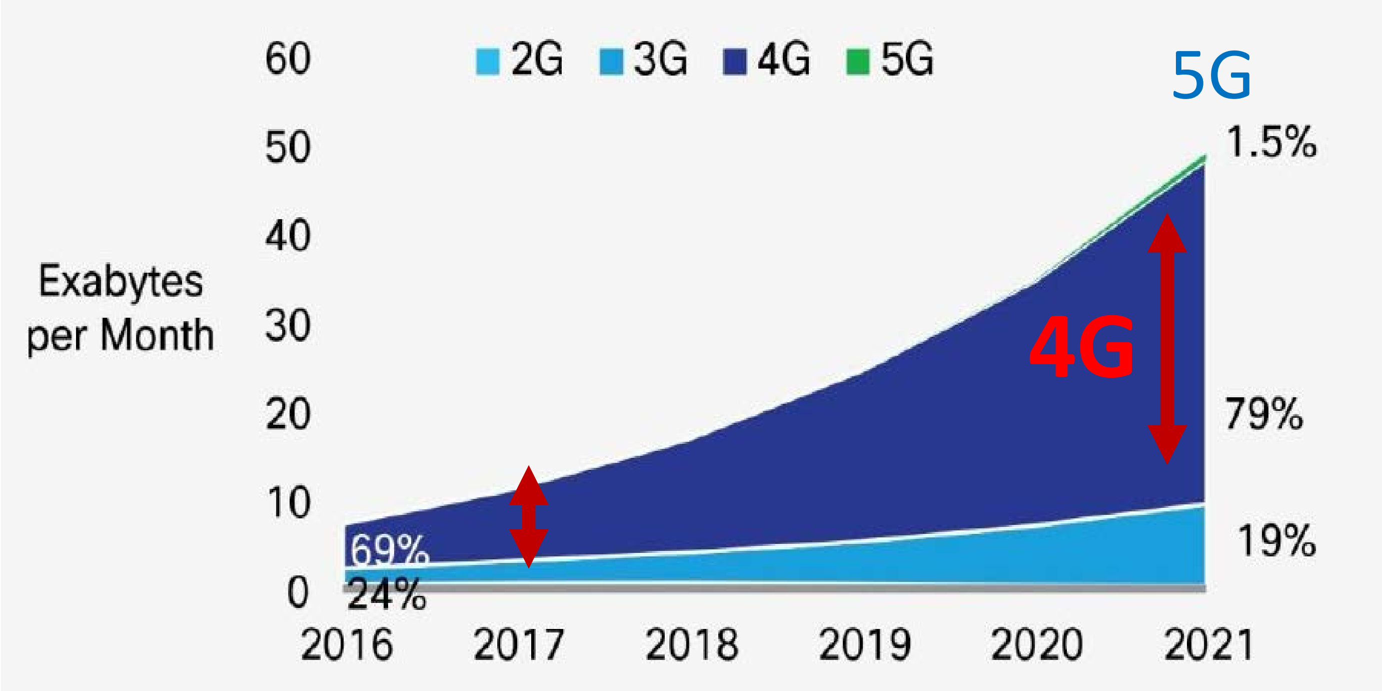
Need for Speed

- From a very recent report from CISCO:
  - 7 times increase in 5 years
  - Compound annual growth rate (CAGR) of 47% per year
  - All portable and smart phone devices are dominating the market and the traffic

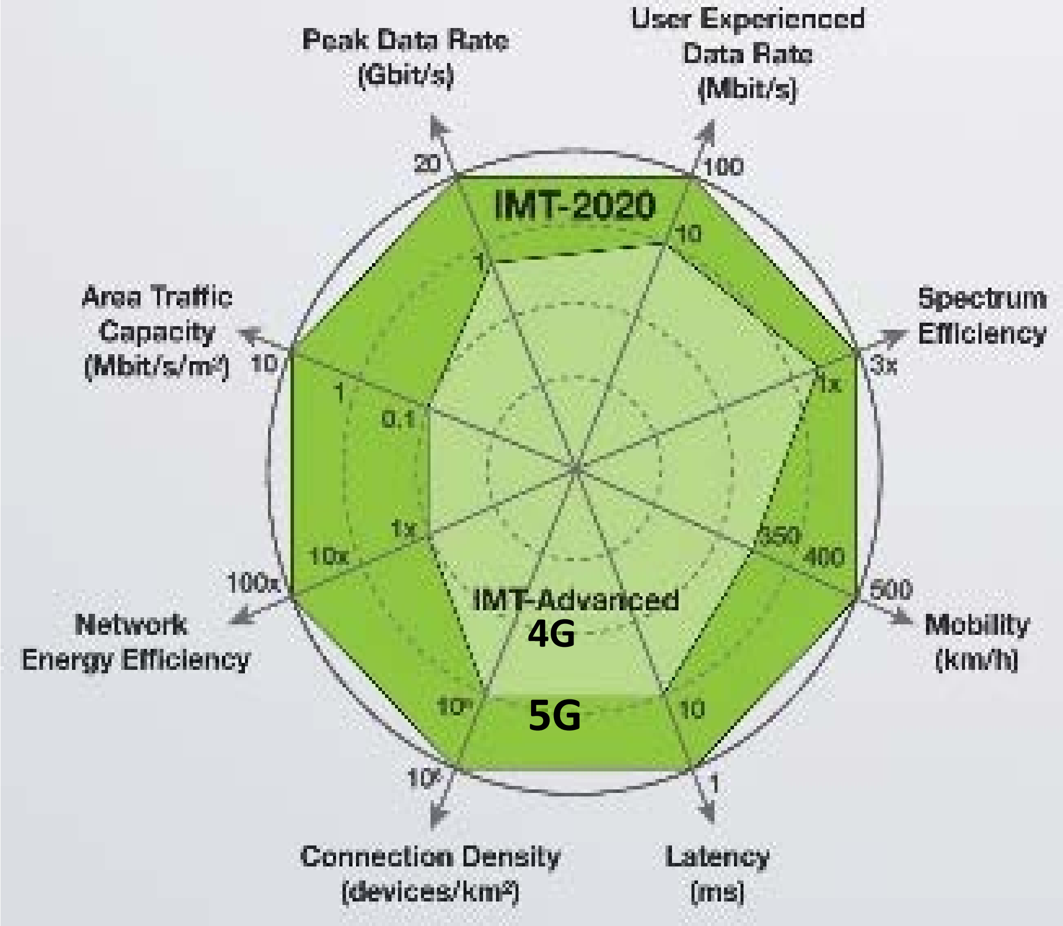




[1] Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2016–2021, Mar. 2017.



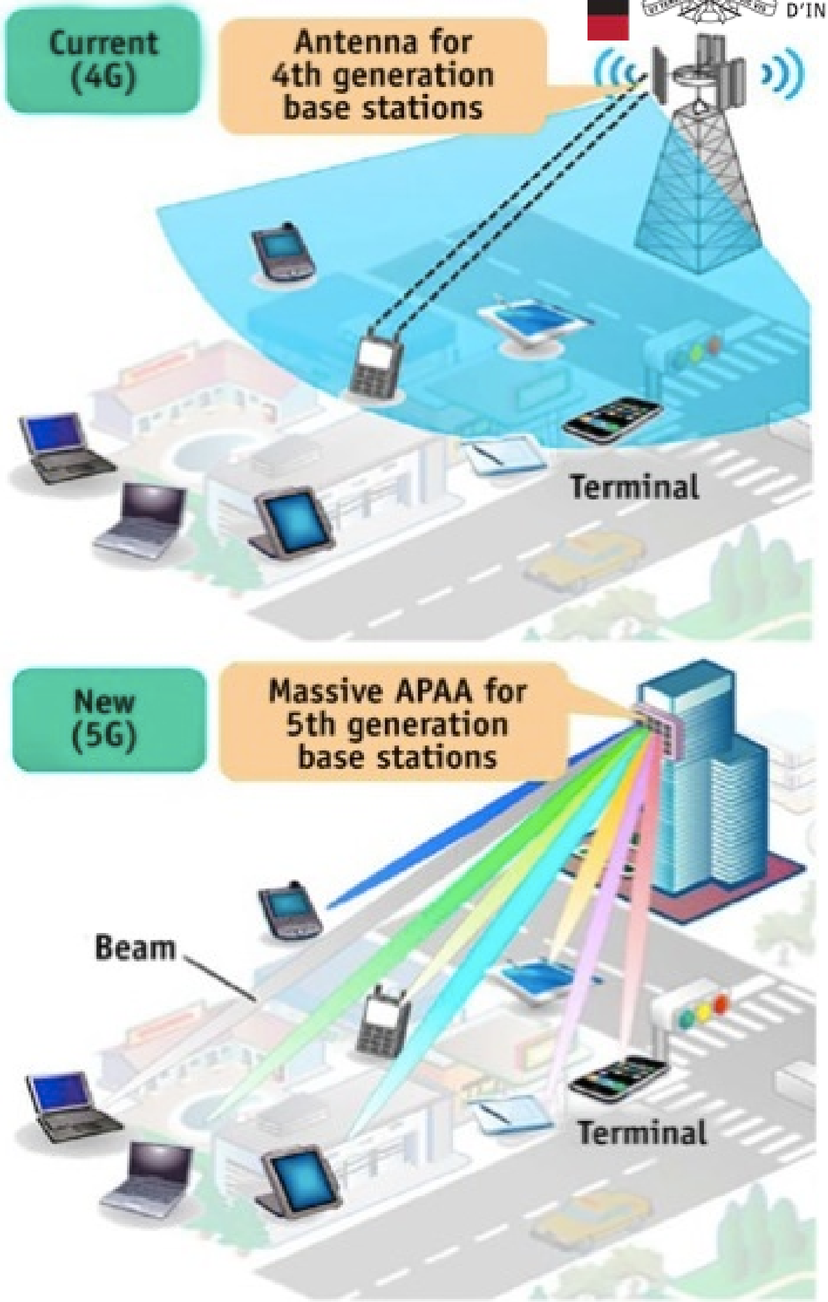
Standard usage of the overall data transfers



Performance Metrics of 5G compared to 4G

5G Networks

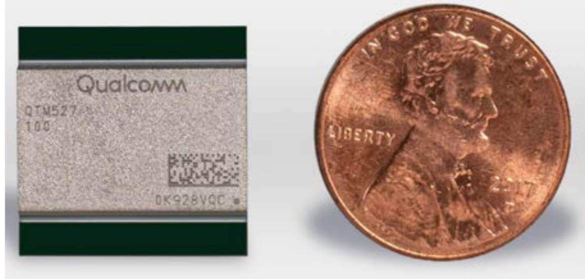
- Very fast speeds/high data rates required (at least 100 times faster than 4G). This means very large operating bandwidths/SNRs are required for antenna systems with low latency.
- Wide-angle beam-scanning is required for 5G network to provide the most optimal speeds for devices in that particular transmission
- Efficient use of frequency spectrum is required for maximizing the capacity and throughput. This requires use of multiple antenna systems, antennas with two orthogonal polarizations, and new innovative coding schemes.


Current (4G)
Antenna for 4th generation base stations
Terminal
New (5G)
Massive APAA for 5th generation base stations
Beam
Terminal

Latest developments …

- Qualcomm Snapdragon 855 chipset, 4G and 5G modem, multi-gigabit connectivity, and can support 4x4 MIMO at 4G and 2x2 MIMO at mm-wave 5G.

… also an Antenna module with 800MHz BW at mm-waves



- Sunrise with Huawei in Switzerland succeeded in achieving 3.67Gpbs of througput using 100MHz of BW in the sub-6GHz bands of 5G using M-MIMO.
- S. Korea has demostrated 5G speeds recently …
- 5G ready smart phones in the market (Pixel, Huawei, Samsung, Xiaomi, Motorola, LG, ect)… what can we ADD!!

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- To achieve such increase in the data rates in the user terminals, several enabling technologies are considered in 4G / 5G systems:
  - (a) Use of Multiple-input-multiple-output (MIMO) systems and Beam-Forming
  - (b) Use of Advanced Modulation and Coding schemes
  - (c) Use Multiple Access Techniques
  - (d) Use of smaller cells (ultra densification) (5G)
  - (e) Device to Device communications (5G)
  - (f) Use of MM-waves (5G)
  - (g) Massive MIMO/Beamforming (5G)

- The channel capacity is a system level metric that needs to be maximized to provide the most possible data throughput to the user terminal. It is a function of the signal power, noise levels, the number of antennas as well as the channel that is affected by antenna field interactions. It can be found using,

N_R X N_R Identity Matrix , R is No. of Rx antennas.

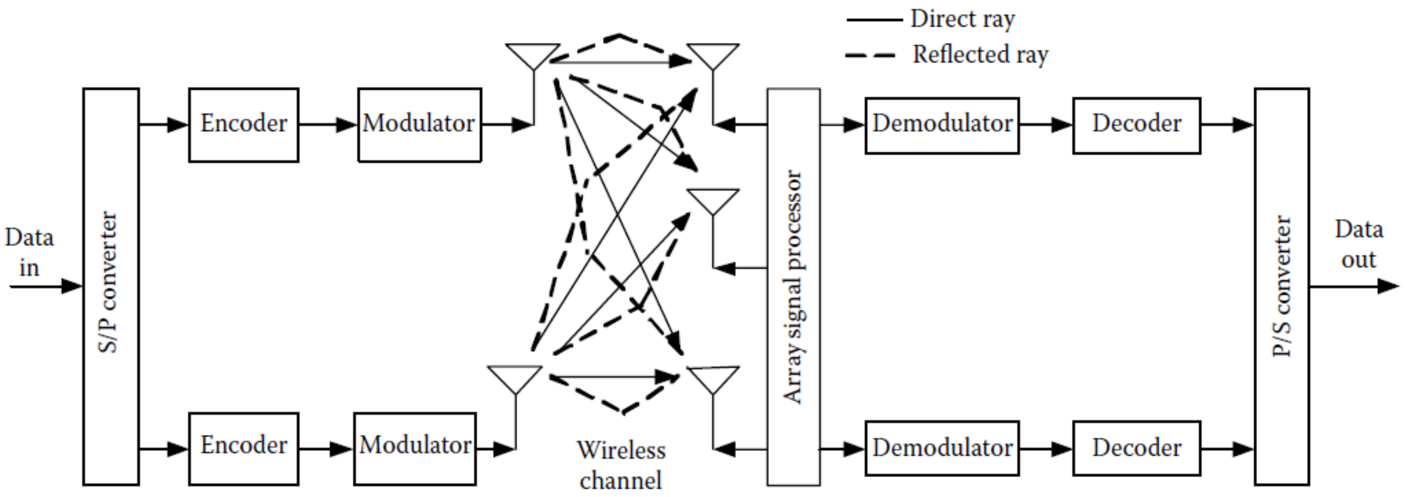
SNR

Channel Matrix

$$C = BW \log_2\left[\det\left(I_R + \frac{\rho}{N_T} HH^T\right)\right]$$

Operating BW

No. Tx Antennas


Direct ray
Reflected ray
Data in
S/P converter
Encoder
Modulator
Encoder
Modulator
Wireless channel
Array signal processor
Demodulator
Decoder
Demodulator
Decoder
P/S converter
Data out

MIMO antenna System block diagram [2]

Placing antennas in close proximity will degrade the MIMO advantage due to coupling and signal correlation [3] →

Low coupling & ECC

High coupling & ECC

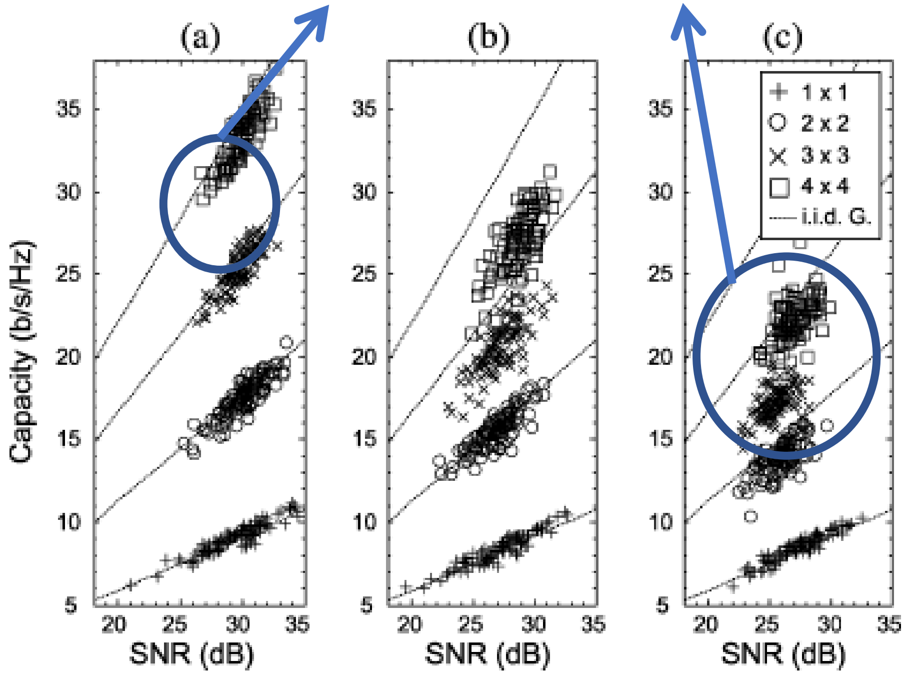


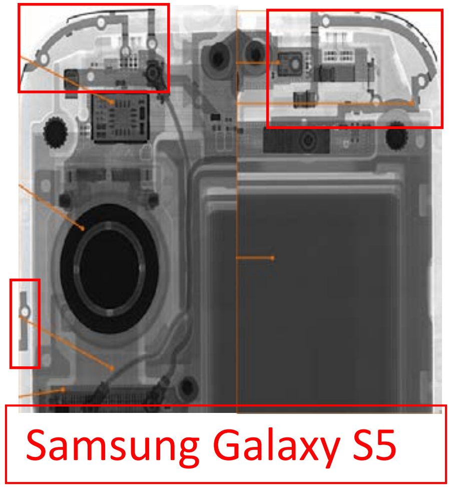
Fig. 11. Measured channel capacity for $\{L \times L | L \in [1, 2, 3, 4]\}$ MIMO cases with dipole arrays for which the dipole separations, denoted $(\Delta_d^{(TX)}, \Delta_d^{(RX)})$, were (a) (λ, λ), (b) $(\lambda/8, \lambda)$, and (c) $(\lambda/8, \lambda/8)$.

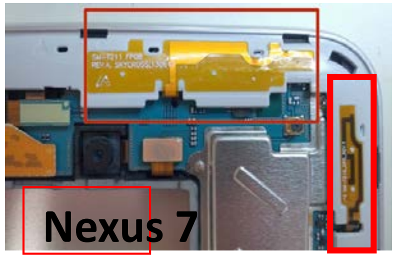
[2] **M. S. Sharawi**, ***Printed MIMO Antenna Engineering***, Artech House 2014.
[3] D. W. Browne, M. Manteghi, M. P. Fitz, and Y. Rahmat-Samii, “Experiments with compact antenna arrays for MIMO radio communications,” *IEEE Trans. Antennas Propag., vol. 54, no. 11, pp. 3239–3250,* Nov. 2006.

Some Standards …

Application	Wireless Standards	Frequency Bands (MHz)	Number of MIMO antennas at UE
Smart phones / tablets	LTE , LTE-A,	700 – 2,600 (multiple bands)	2 / 4
Laptops /PCs	802.11n,	2,450 / 5,800	2 / 4
USB dongles	802.11ac,	5,200 4,500	2 / 4 / 8
V2V	802.16m,	2,300 / 2,500 / 3,500	2
	802.11ad,	60,000	4 / 8 / ?
	DSRC	5,900	
	802.11aj	45,000 / 60,000	
	5G?	28,000 / 38,000	

Huawei P9


Samsung Galaxy S5


Nexus 7

→ **Multi-band and Multi-antenna systems are essential!**

MIMO antenna designs

- The ultimate goal is to have Higher channel Capacity
  - Port isolation (S21) should be minimized, so that higher port efficiency is achieved
  - Field correlation (ECC) should be minimized, so that channel paths are independent to have higher "C"
- A Major misconception: "Higher port isolation, provides lower ECC"!!

$$\rho_e = \frac{\left|\iint_{4\pi}\left[\vec{F}_1(\theta,\varphi) * \vec{F}_2(\theta,\varphi)\right]d\Omega\right|^2}{\iint_{4\pi}\left|\vec{F}_1(\theta,\varphi)\right|^2 d\Omega \iint_{4\pi}\left|\vec{F}_2(\theta,\varphi)\right|^2 d\Omega}$$

Isotropic channel

[4] S. Blanch, J. Romeu and I. Corbella, "Exact representation of antenna system diversity performance from input parameter description", *IET Electronic Letters*, **39**, 9, May 2003, pp. 705-707.

- The correlation coefficient can be extracted from the s-parameter measurements according to [4], [5] ONLY for highly efficient MIMO antenna systems:

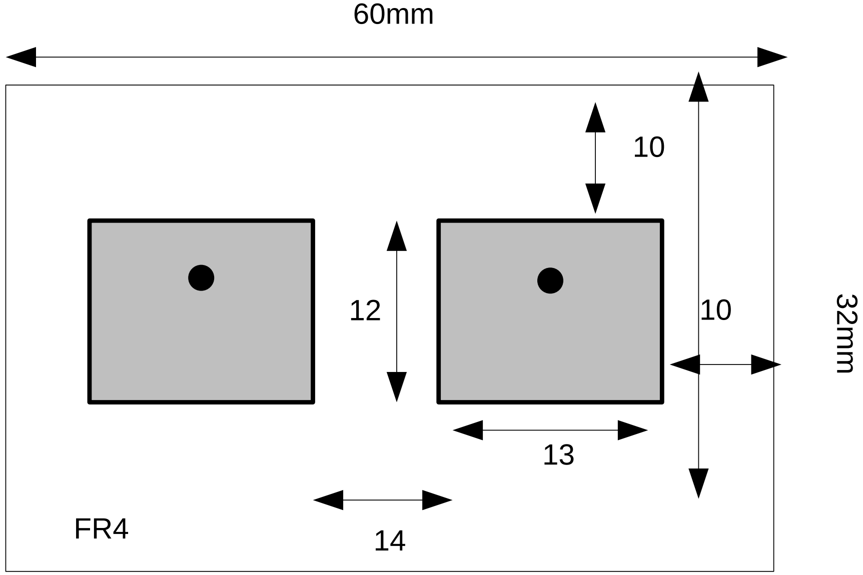
$$\xcancel{\rho_{env} = \frac{|S_{11}^* S_{12} + S_{21}^* S_{22}|^2}{(1-(|S_{11}|^2+|S_{21}|^2))(1-(|S_{22}|^2+|S_{12}|^2))}}$$

$$\rho_{env} = \frac{|S_{11}^* S_{12} + S_{21}^* S_{22}|^2}{(1-(|S_{11}|^2+|S_{21}|^2))(1-(|S_{22}|^2+|S_{12}|^2)\eta_1\eta_2)}$$

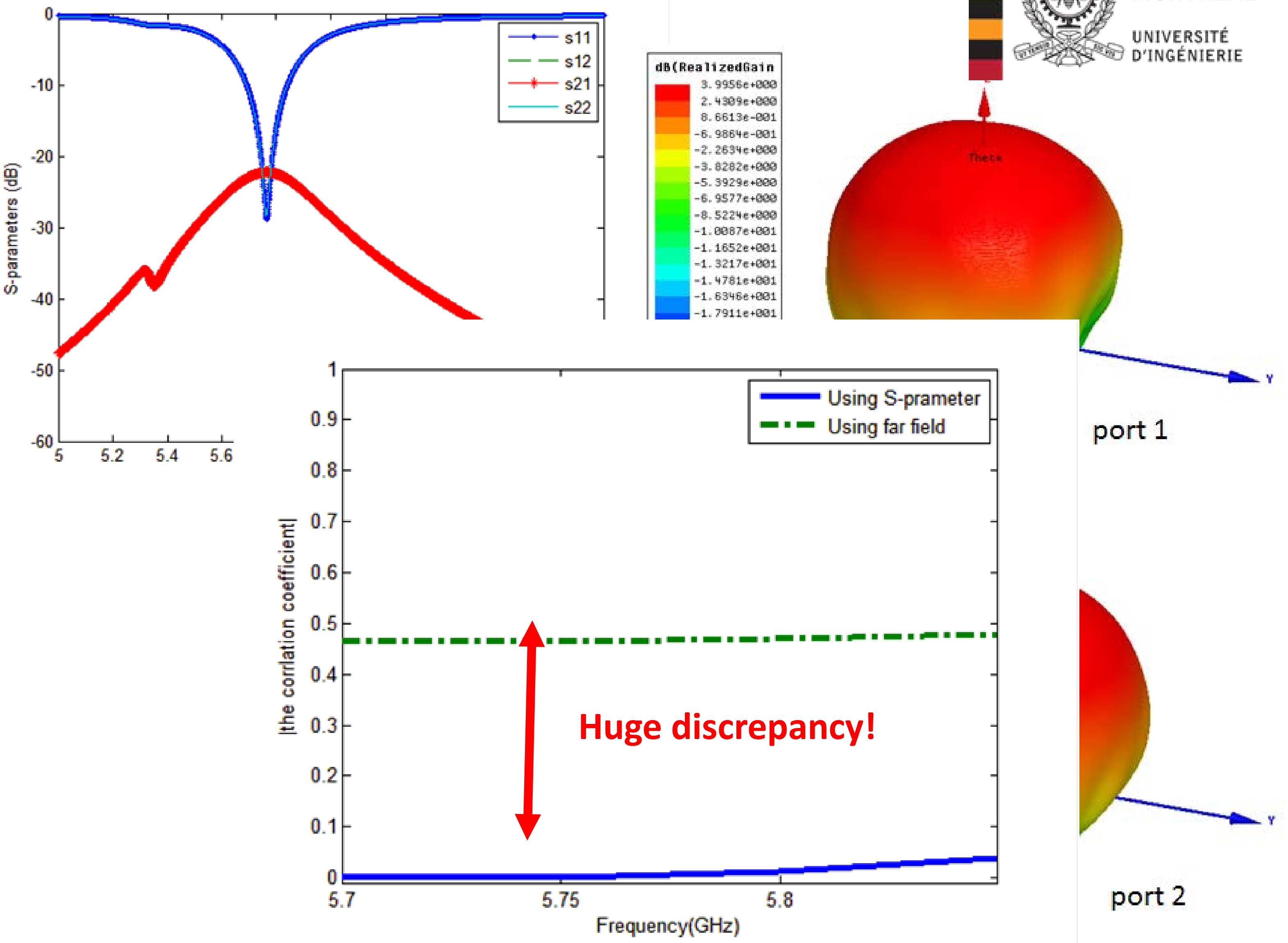
- A value of ρ less than 0.3 is needed for good diversity performance as per LTE Release 8 specs.

[5] P. Hallbjorner, "The significance of Radiation efficiencies when using the S-parameters to Calculate the Received Signal Correlation from two Antennas," *IEEE Antennas and Wireless Propagation Letters*, Vol. 4, pp. 97-99, 2004.

- Simple Example:



5.8 GHz patch based MIMO antenna system [6]



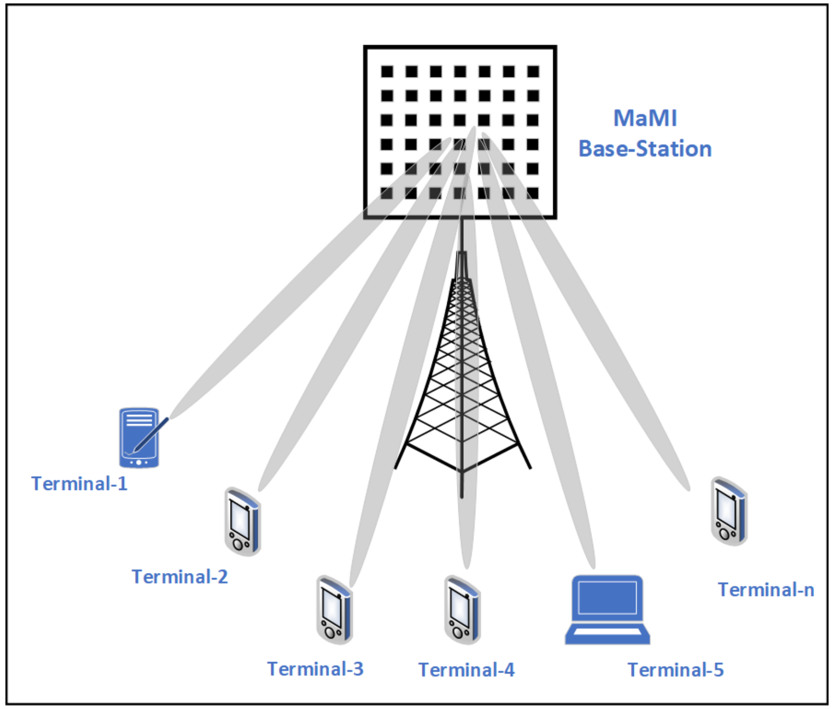
Huge discrepancy!

[6] **M. S. Sharawi**, "Printed MIMO Antenna Systems: Current Misuses and Future Prospects," *IEEE Antennas and Propagation Magazine*, Vol. 59, No. 2, pp. 162-170, April 2017.

[7] **M. S. Sharawi,** A. Hasan and M. U. Khan, "Correlation Coefficient Calculations for MIMO Antenna Systems: A Comparative Study," *International Journal on Microwave and Wireless Technology*, Volume 9, Issue 10, pp. 1991-2004 December 2017.

Massive-MIMO advantages

- The ultimate goal is to have Higher channel Capacity
- Massive MIMO (m-MIMO or MaMI) will have:
  - Capacity Improvement (higher SNR, channels and BW)
  - Energy efficiency (higher directivity, lower power waste, use of linear codes due to asymptotic behavior of large matrices)
  - Use of in-expensive low power components (power is combined)
  - Should have reduction in latency
  - Robustness against jamming (directed beams)



Complex channel matrix

SNR

Large number of transmit antennas

$$\begin{cases} \left(\dfrac{GG^{\mathrm{H}}}{n_{\mathrm{t}}}\right)_{n_{\mathrm{t}} \gg n_{\mathrm{r}}} \approx I_{n_{\mathrm{r}}}, \\ C_{n_{\mathrm{t}} \gg n_{\mathrm{r}}} \approx \log_2 \det(I_{n_{\mathrm{r}}} + \rho \cdot I_{n_{\mathrm{r}}}) \\ \qquad = n_{\mathrm{r}} \cdot \log_2(1 + \rho), \end{cases}$$

[8] F. Rusek, D. Persson, B. K. Lau, E. G. Larsson, T. L. Marzetta, O. Edfors and F. Tufvesson, "Scaling up MIMO: Opportunities and Challenges with very Large Arrays", IEEE Signal Processing Magazine, Vol. 30, No. 1, pp. 40-60, January 2013.

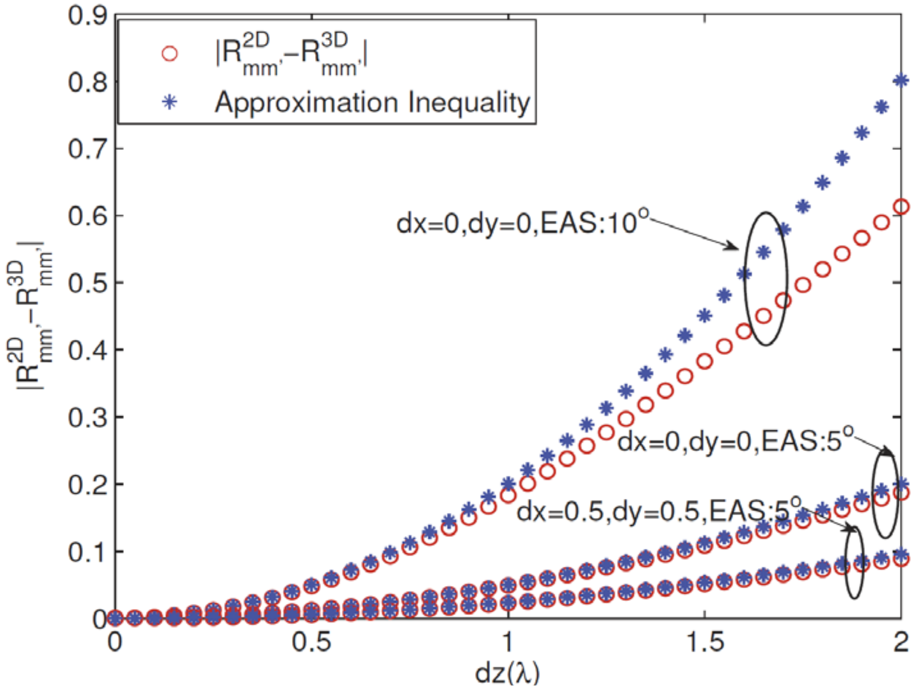
3D Massive-MIMO advantage

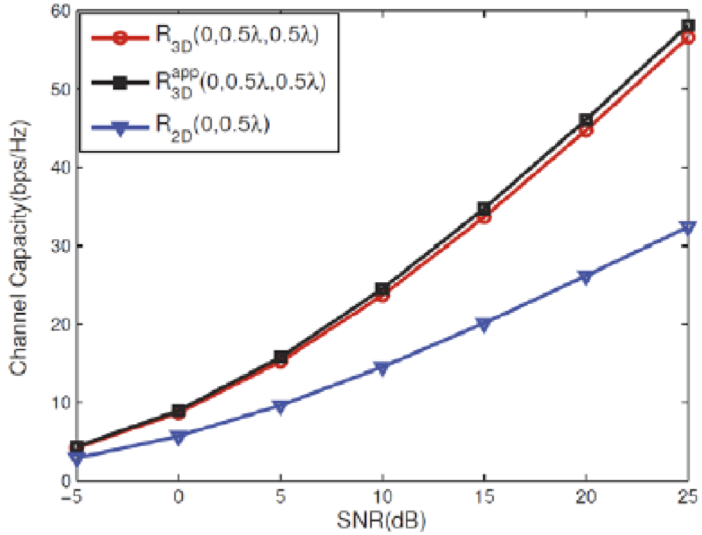
- Majority of theoritical works assumed azimuthal beam distributions at the BS, this did not give the correct picture of the channel behaviour and benifits of MaMI.

$$R_{mm'}^{3D} = \begin{cases} \dfrac{\mathbb{E}\left\{A_V(\theta)A_H(\phi)e^{\left[-j2\pi r_{Tx,c,l}^{T}(d_m-d_{m'})\right]}\right\}}{\mathbb{E}\{A_V(\theta)\}\mathbb{E}\{A_H(\phi)\}} & ,for\ \ \xi_m = \xi_{m'} \\ 0 & ,for\ |\xi_m - \xi_{m'}| = \dfrac{\pi}{2} \end{cases}$$

$$R_{mm'}^{2D} = \begin{cases} \dfrac{\mathbb{E}\left\{A_H(\phi)e^{\left[-j2\pi r_{Tx,c,l}^{T}(d_m-d_{m'})\right]}\right\}}{\mathbb{E}\{A_H(\phi)\}} & ,for\ \ \xi_m = \xi_{m'} \\ 0 & ,for\ |\xi_m - \xi_{m'}| = \dfrac{\pi}{2} \end{cases}$$

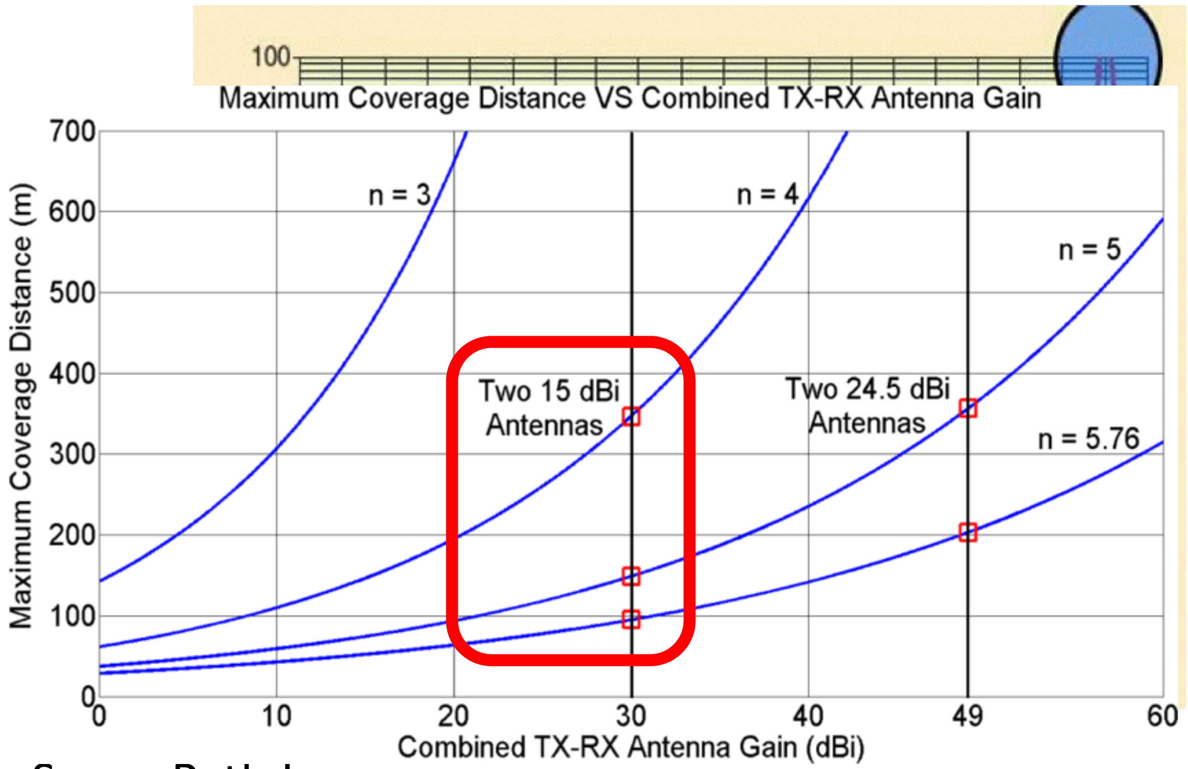
$$R_{mm'}^{2D}(dx,dy) - R_{mm'}^{3D}(dx,dy,dz) \approx \frac{2\pi^2 dz^2 \epsilon^2}{3} R_{mm'}^{2D}(dx,dy)$$





mm-wave advantage

- More BW is available at mm-wave bands
- FCC recently approved 28/38 GHz bands with at least ~1 GHz BW, in addition to the 60GHz ISM band.
- Free-space path loss at 28/38 GHz is not that bad, and these bands were proven to be useful for mobile communications.



Free Space Path Loss (FSPL) is very small, and can be accounted for by using antenna arrays!

Suitability of mm-wave bands for wireless communications @ 28GHz

[9] T. Rappaport, et. al., “Millimeter Wave Mobile Communications for 5G Cellular: It Will Work!,” *IEEE Access*, Vol. 1, pp. 335-349, January 2013.

Potential Antenna Design challenges

- Integration of antenna systems (sub-6GHz and mm-waves) with other electronics, form-factor, mechanical
- multi-band coverage (GPS L1/L5, WLAN 2.4/5.2/5.8, NFC 13.56MHz, 2G/3G/4G/5G NR) for sub-6GHz
- Metal-clearances, wide-band matching with good efficiency, BW, EIRP and SAR
- coming up with work-arounds to handset holding gestures
- dual-polarized mm-wave arrays with good isolation, coexistence with sub-6GHz, SAR levels at mm-waves, Human body impact on mm-wave antenna performance
- MIMO at sub-6GHz and at mm-waves
- Characterization and testing methods

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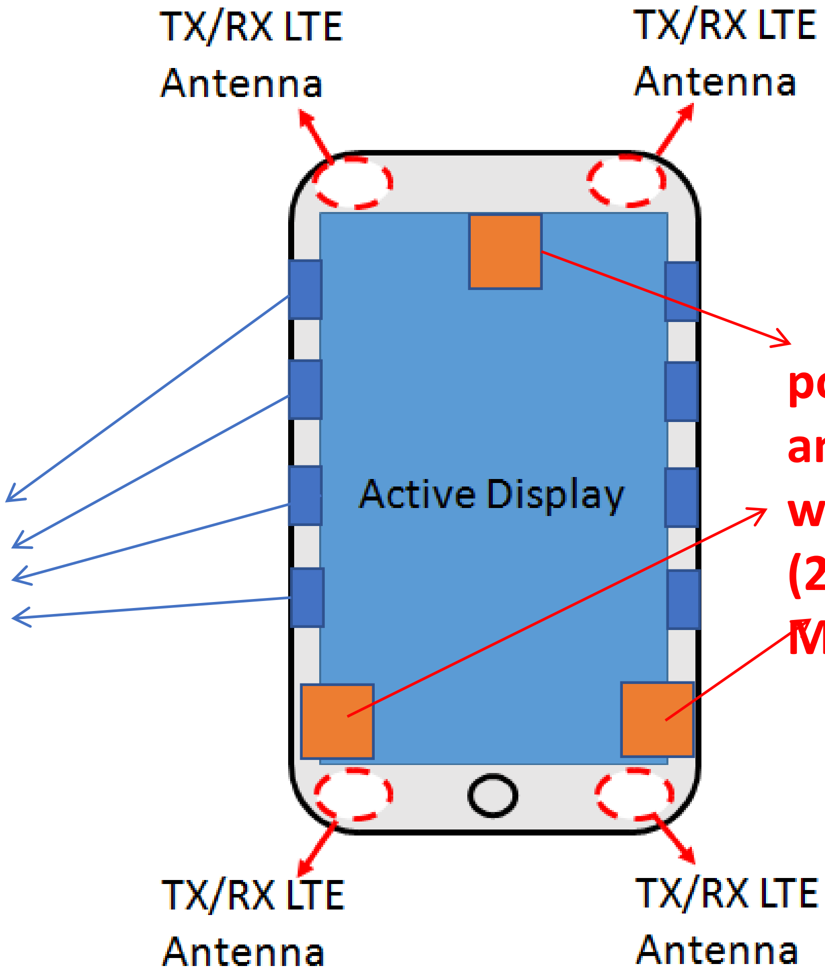
- **Some technologies/designs for future 5G terminals**:
  - (A) Reconfigurable antennas for cellular and Cognitive Radio (CR) platforms
  - (B) Active Antennas (5G: 3.6 / 4.5 GHz)
  - (C) Use of mm-wave antenna systems (5G: 28 / 38 / 44 / 60 GHz)
  - (D) CAA based integrated antennas (4G / 5G)
  - (E) Massive-MIMO (M-MIMO, or MaMi)? (4G / 5G)

→ **Innovative antenna designs and structures that are efficient and easily integrated**

5G handset antennas?

4G
LTE-A possible antennas and locations to support 4x4 MIMO.
(700 MHz – 2600 MHz)

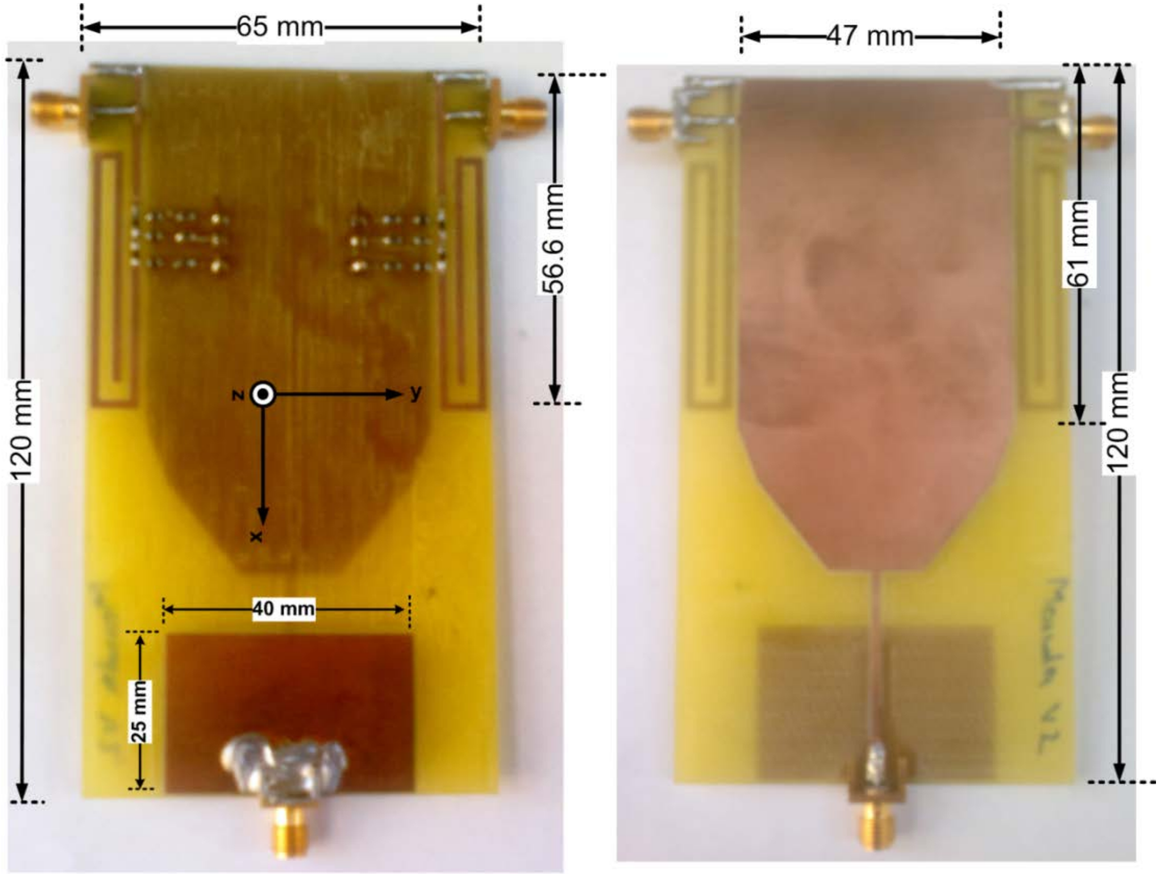
5G
possible antennas and locations to support 8x8 MIMO.
(3600 / 4500 MHz) ??


TX/RX LTE Antenna
TX/RX LTE Antenna
Active Display
TX/RX LTE Antenna
TX/RX LTE Antenna

5G
possible antennas and locations mm-wave arrays
(28,000 / 38,000 MHz) ??

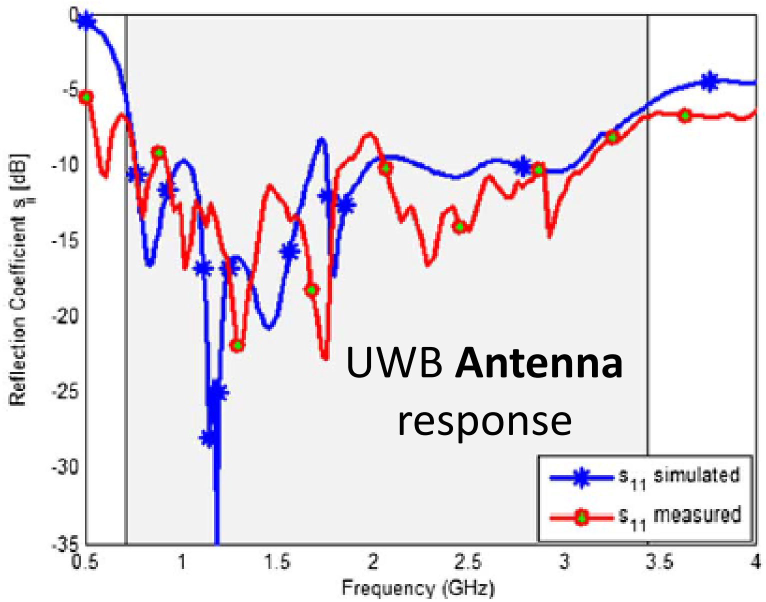
(A) Reconfigurable MIMO Antennas for cellular and Cognitive Radio Platforms

- A 2-element Reconfigurable MIMO Antenna based on Meandered inverted-F geometries [10]
- The first integrated UWB-MIMO antenna system (Sensing-Communication) covering **700-3000 MHz** in a small form factor.
- **Two modes** of operation:
  - 1.1 / 2.48 GHz (100 MHz BW)
  - 0.585 / 0.86 / 2.41 GHz (22 / 90 / 120 MHz BW)

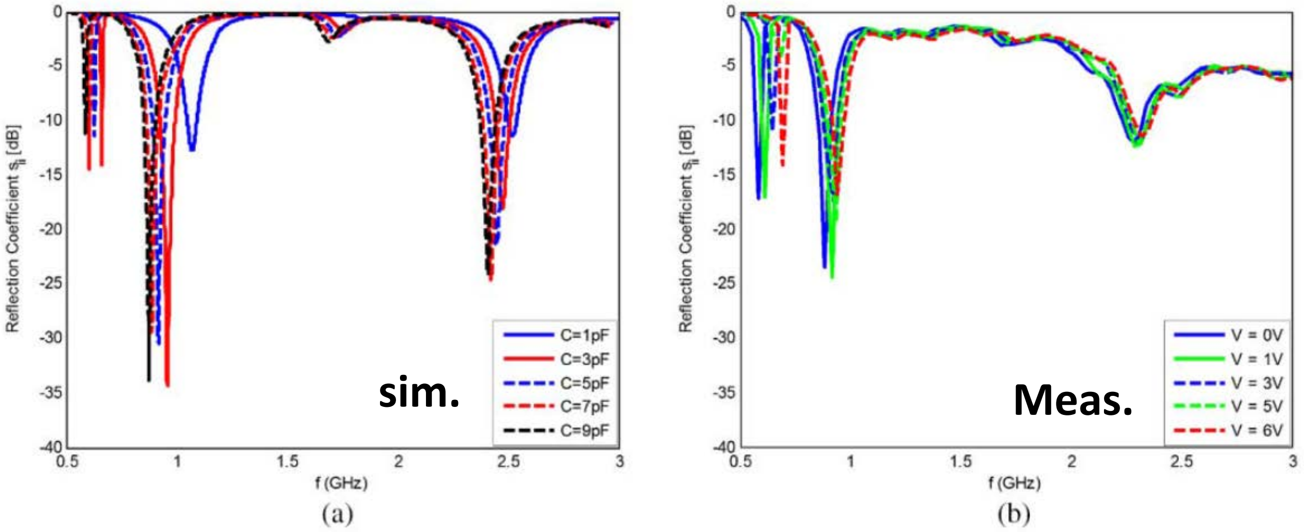


(a) (b)

[10] R. Hussain and **M. S. Sharawi**, “A Cognitive Radio Reconfigurable MIMO and Sensing Antenna System,” IEEE Antennas and Wireless Propagation Letters, Vol. 14, pp. 257-260, 2015.



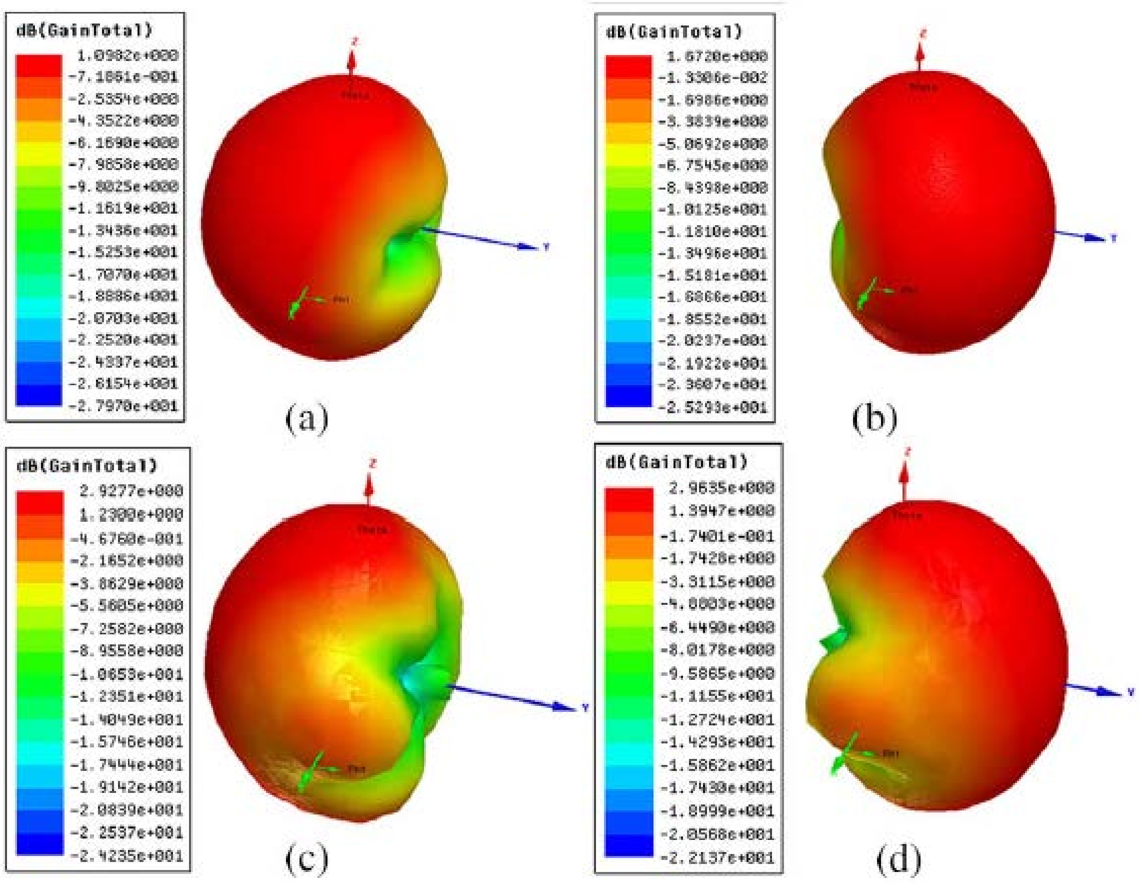
UWB **Antenna** response



(a)

(b)

Mode-2 responses


dB(GainTotal)
1.0982e+000
-7.1861e-001
-2.5354e+000
-4.3522e+000
-6.1690e+000
-7.9858e+000
-9.8025e+000
-1.1619e+001
-1.3436e+001
-1.5253e+001
-1.7070e+001
-1.8886e+001
-2.0703e+001
-2.2520e+001
-2.4337e+001
-2.6154e+001
-2.7970e+001
dB(GainTotal)
1.6720e+000
-1.3306e-002
-1.6986e+000
-3.3839e+000
-5.0692e+000
-6.7545e+000
-8.4398e+000
-1.0125e+001
-1.1810e+001
-1.3496e+001
-1.5181e+001
-1.6866e+001
-1.8552e+001
-2.0237e+001
-2.1922e+001
-2.3607e+001
-2.5293e+001
dB(GainTotal)
2.9277e+000
1.2300e+000
-4.6760e-001
-2.1652e+000
-3.8629e+000
-5.5605e+000
-7.2582e+000
-8.9558e+000
-1.0653e+001
-1.2351e+001
-1.4049e+001
-1.5746e+001
-1.7444e+001
-1.9142e+001
-2.0839e+001
-2.2537e+001
-2.4235e+001
dB(GainTotal)
2.9635e+000
1.3947e+000
-1.7401e-001
-1.7428e+000
-3.3115e+000
-4.8803e+000
-6.4490e+000
-8.0178e+000
-9.5865e+000
-1.1155e+001
-1.2724e+001
-1.4293e+001
-1.5862e+001
-1.7430e+001
-1.8999e+001
-2.0568e+001
-2.2137e+001
z
y

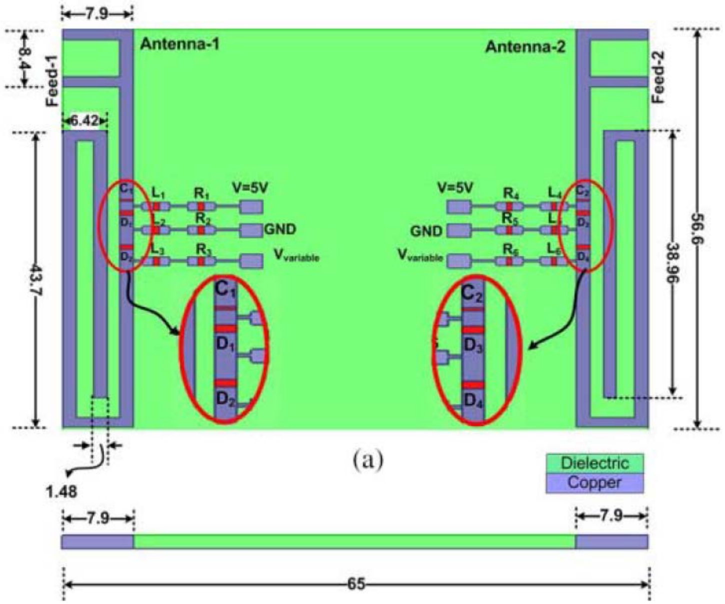
(a)

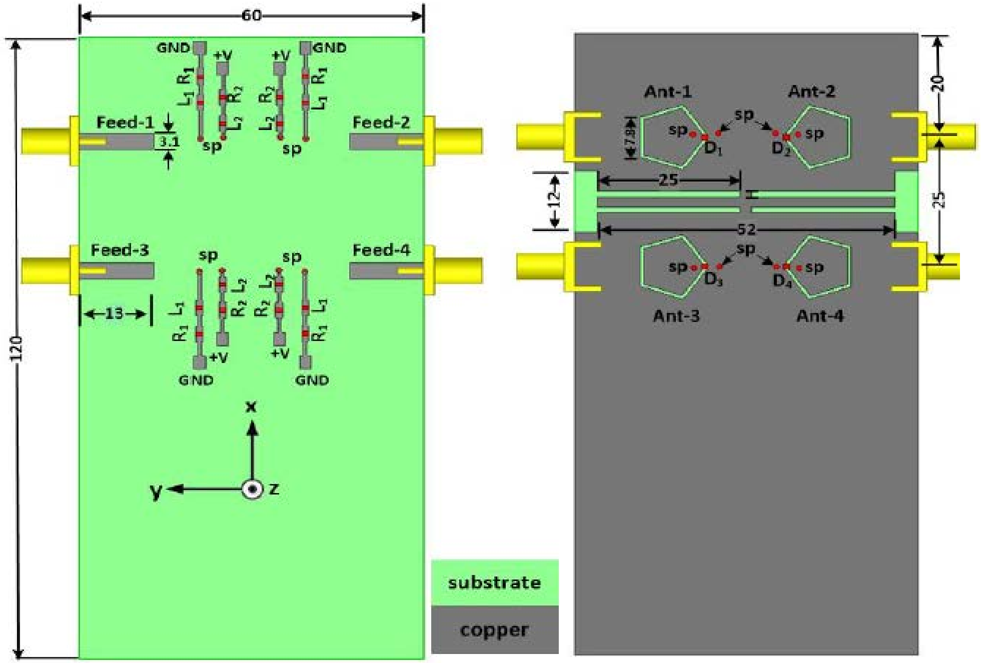
(b)

(c)

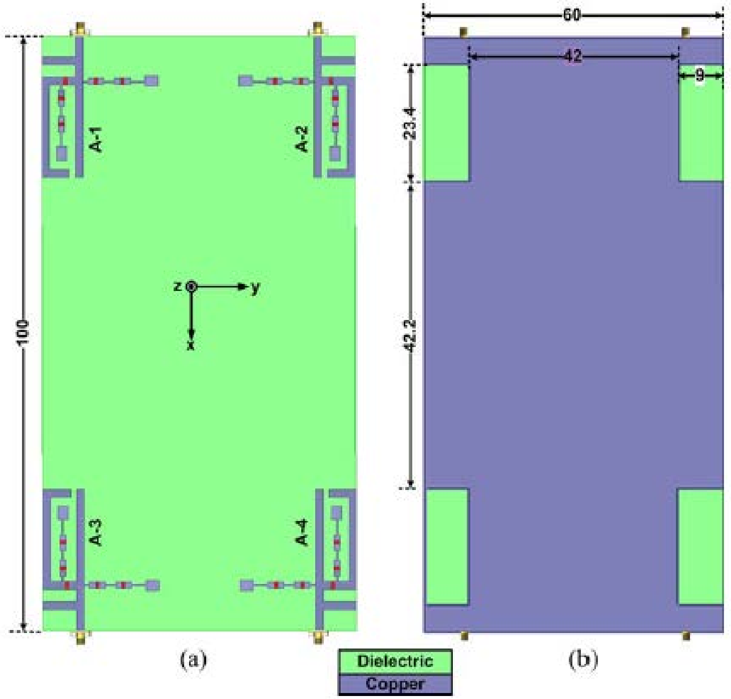
(d)

- More reconfigurable MIMO antennas for cellular and CR platforms from AMSDL-KFUPM …


7.9
8.4
Feed-1
Antenna-1
Antenna-2
Feed-2
6.42
43.7
56.6
38.96
L1 R1 V=5V
L2 R2 GND
L3 R3 Vvariable
V=5V R4 L4
GND R5 L5
Vvariable R6 L6
C1 D1 D2
C2 D3 D4
1.48
(a)
Dielectric
Copper
7.9
65

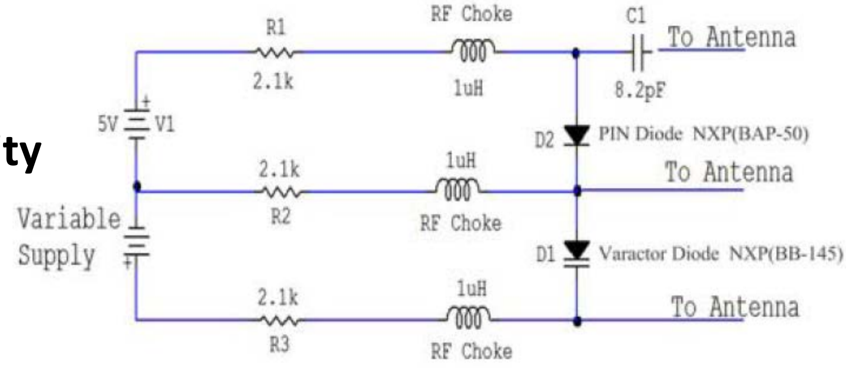

60
120
GND +V R1 R2 L1 L2 sp
Feed-1
Feed-2
3.1
Feed-3
Feed-4
13
+V GND
x
y
z
substrate
copper
Ant-1
Ant-2
Ant-3
Ant-4
sp
D1 D2 D3 D4
7.8
25
12
52
20
25

← **Hexagonal based Reconfigurable MIMO**


A-1
A-2
A-3
A-4
100
z
y
x
(a)
Dielectric
Copper
60
42
9
23.4
42.2
(b)

Shorted microstrip based Reconfigurable MIMO

↑ **Biasing Circuit** →
0-6V bias voltage for frequency reconfigurability

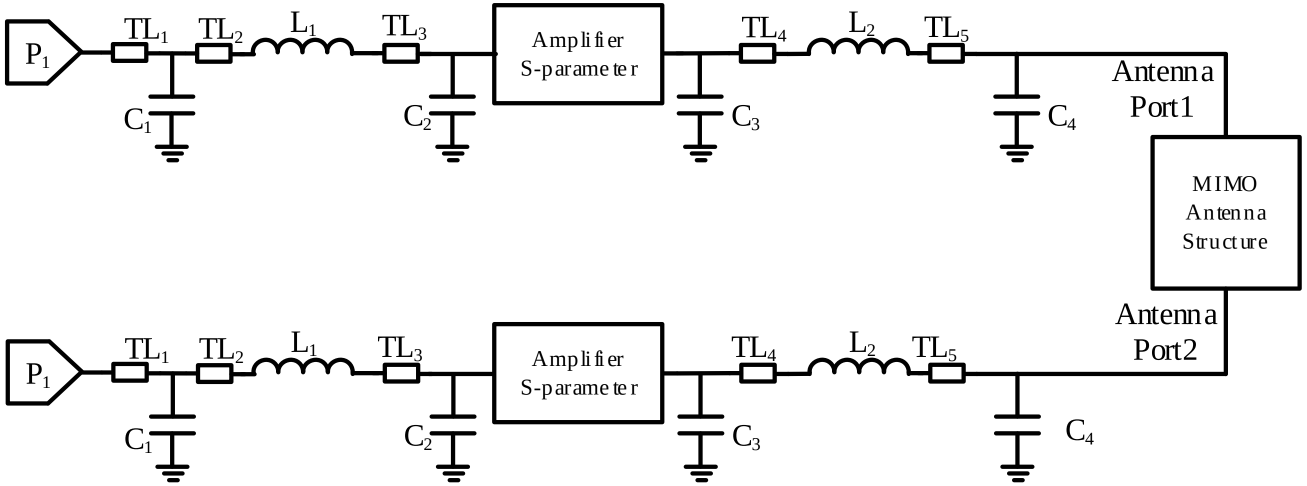

R1
2.1k
RF Choke
1uH
C1
8.2pF
To Antenna
5V V1
D2 PIN Diode NXP(BAP-50)
2.1k
1uH
To Antenna
R2
RF Choke
Variable Supply
D1 Varactor Diode NXP(BB-145)
2.1k
1uH
To Antenna
R3
RF Choke

Potential challenges

- Miniaturization of the UWB antenna to fit within small form factor devices
- Achieving large BW within the communication MIMO elements
- Simultaneous operation of the two and integration with active components and actual sensing algorithms
- Integration issues (device shape, hand gesture, radome, etc.)
- Coexistence with other antenna systems and bands
- Novel designs on the periphery of devices rather than inside (?)

(B) Active MIMO Antennas Systems

- A **New co-design approach** that does not require 50-ohm sub-systems [11], [12]
- The **first active Integrated UWB MIMO** antenna Covering 1.8-5.8 GHz
- Improved efficiency, isolation, size and ECC.
- **AIA are needed for 5G** to enhance energy efficiency requirements


P_1
TL_1
TL_2
L_1
TL_3
Amplifier S-parameter
TL_4
L_2
TL_5
C_1
C_2
C_3
C_4
Antenna Port1
MIMO Antenna Structure
Antenna Port2
P_1
TL_1
TL_2
L_1
TL_3
Amplifier S-parameter
TL_4
L_2
TL_5
C_1
C_2
C_3
C_4

- C_1=C_4=0.1pF, C_2=0.4pF, C_3=0.7pF, L_1=1nH, L_2=0.5nH
- TL_1=10mm and TL_2=TL_3=TL_4=TL_5=3mm and W=1.7mm.

[11] S. Dhar, O. Hammi, **M. S. Sharawi** and F. M. Ghannouchi "An Active Integrated Ultrawideband MIMO Antenna," IEEE Transactions on Antennas and Propagation, Vol. 64, No. 4, pp. 1573-1578, April 2016.

[12] **M. S. Sharawi,** S. K. Dhar, O. Hammi and F. Ghannouchi, "Miniaturized Active Integrated Antennas: A Co-Design Approach," IET Microwaves, Antennas and Propagation, Vol. 10, No. 8, pp. 871-879 , Aug. 2016

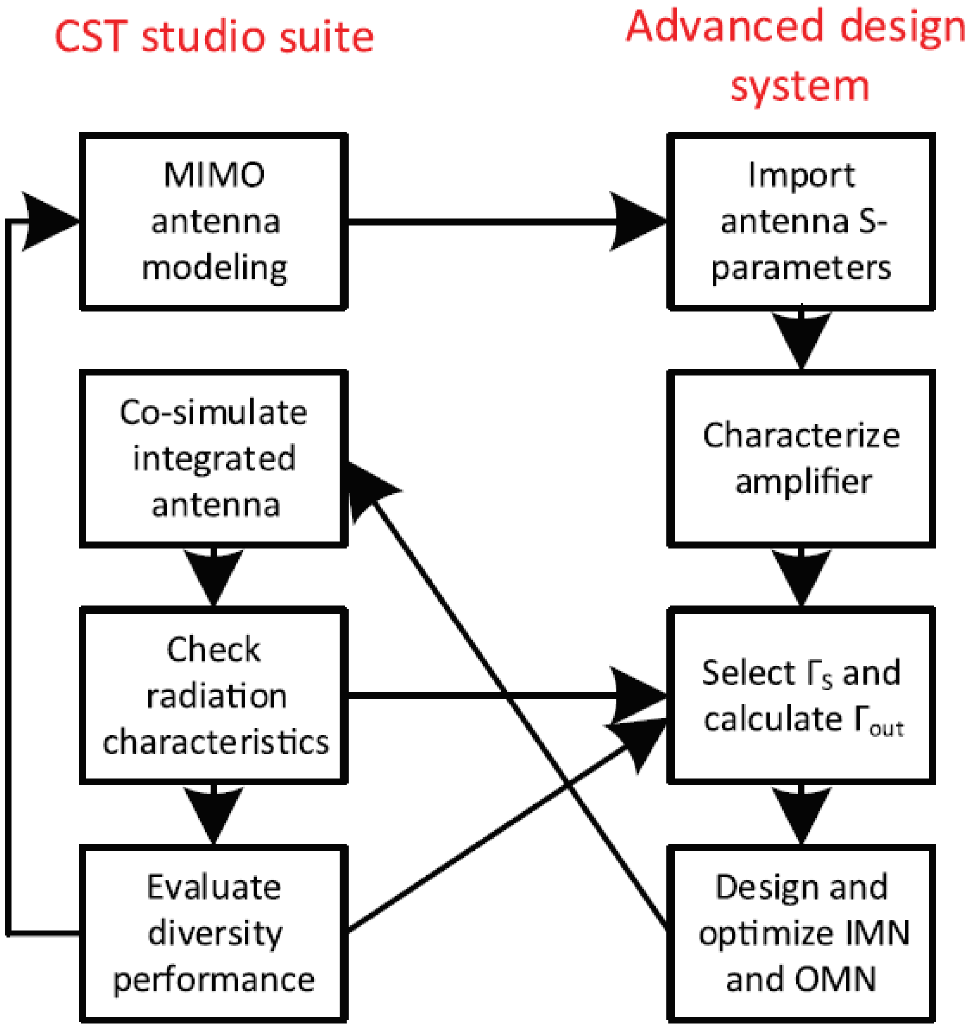
(1)MIMO Antenna design (CST)

(2)Optimized (Γout, Γs) of transistor based on noise and gain circles (ADS)

(3)IMN and OMN are designed to match 50 (system input) to Γs and Γant to ΓL= Γ*out

(4)Co-simulate complete system and fine tune for gain and BW (CST-MS, CST-DS)

* Antenna is converted to a 2-port network in ADS sims. to account for its effect.



CST studio suite

Advanced design system

MIMO antenna modeling

Co-simulate integrated antenna

Check radiation characteristics

Evaluate diversity performance

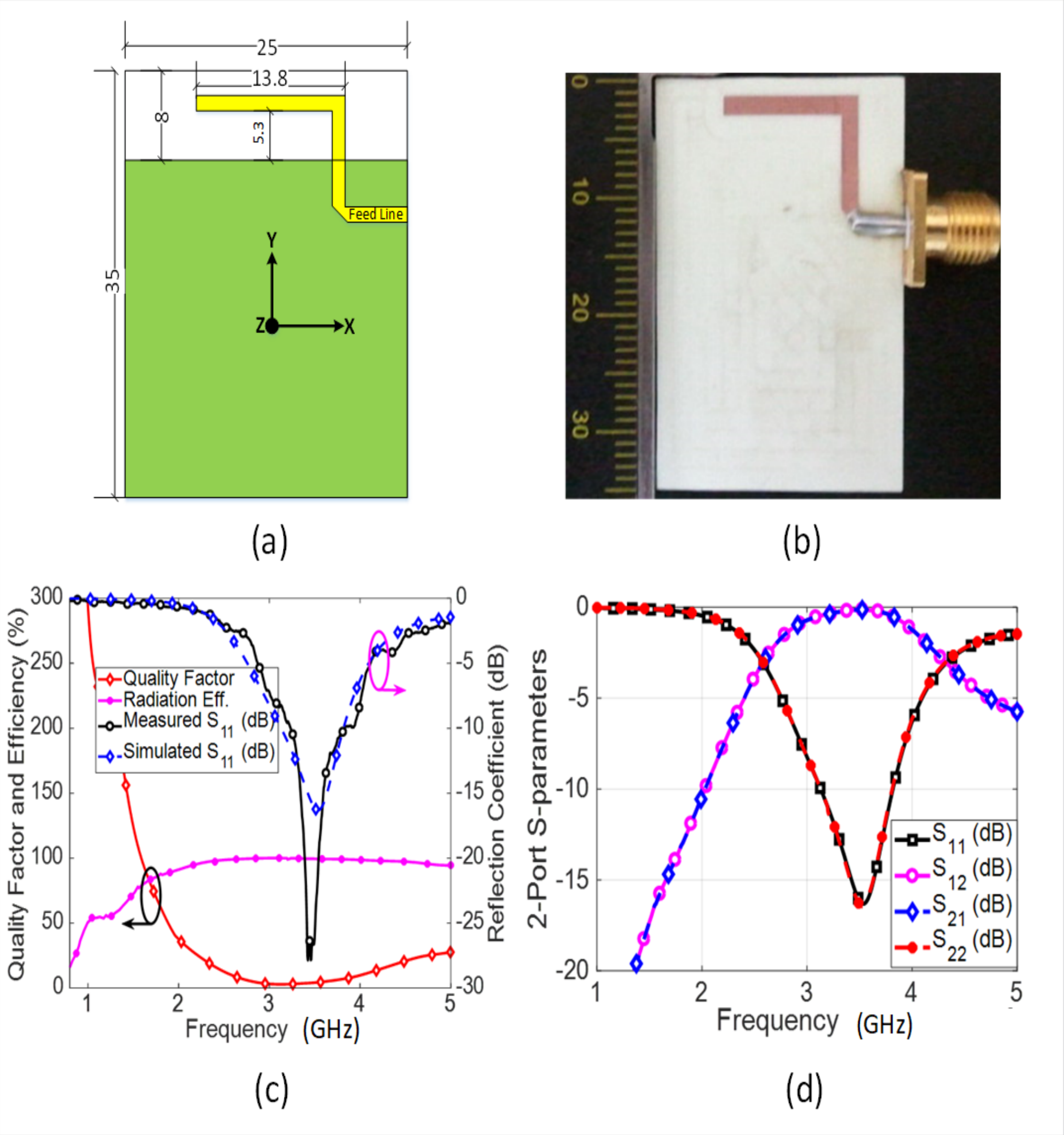
Import antenna S-parameters

Characterize amplifier

Select Γ_S and calculate Γ_{out}

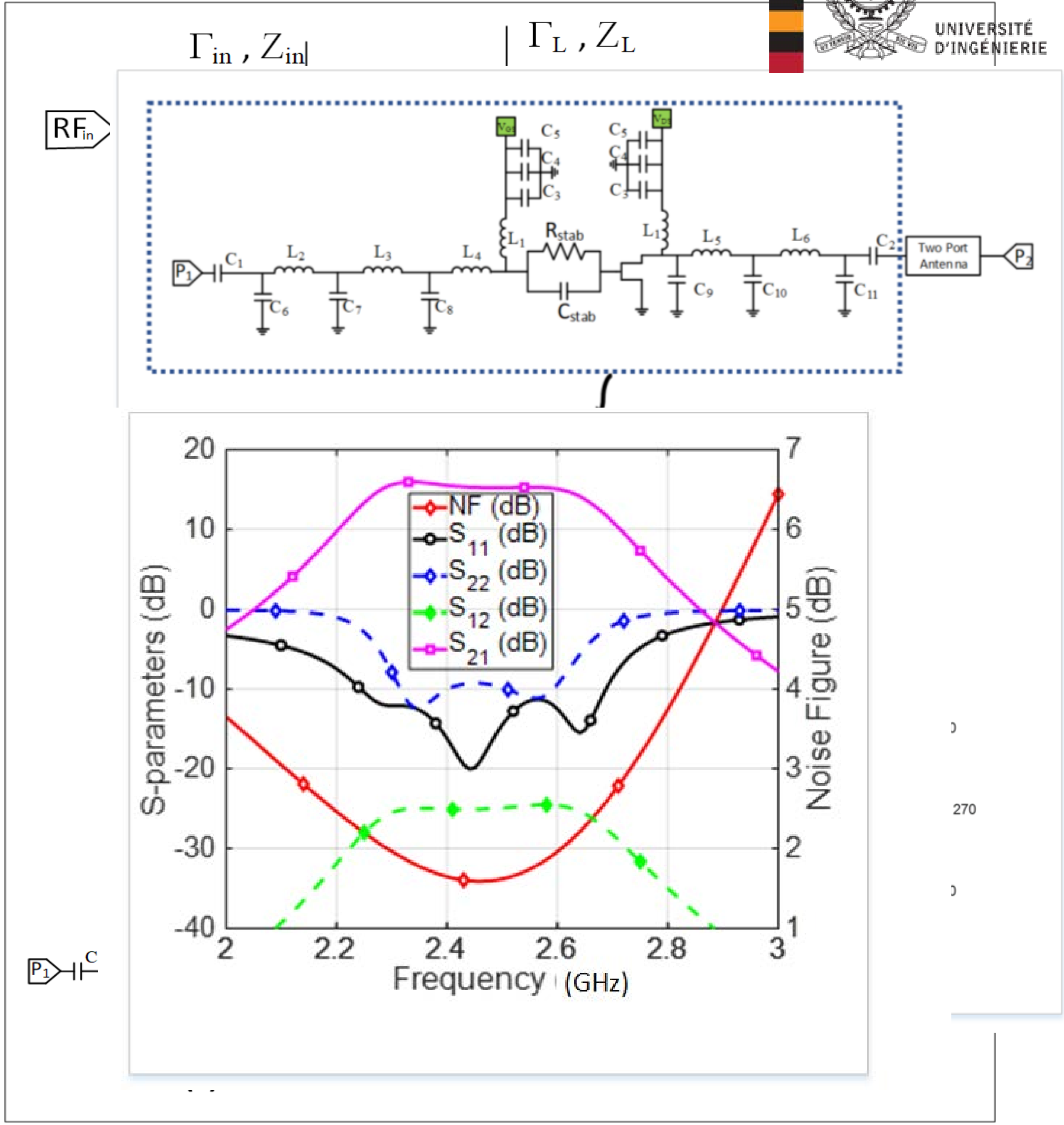
Design and optimize IMN and OMN

A monopole AIA 2.3-2.6 GHz

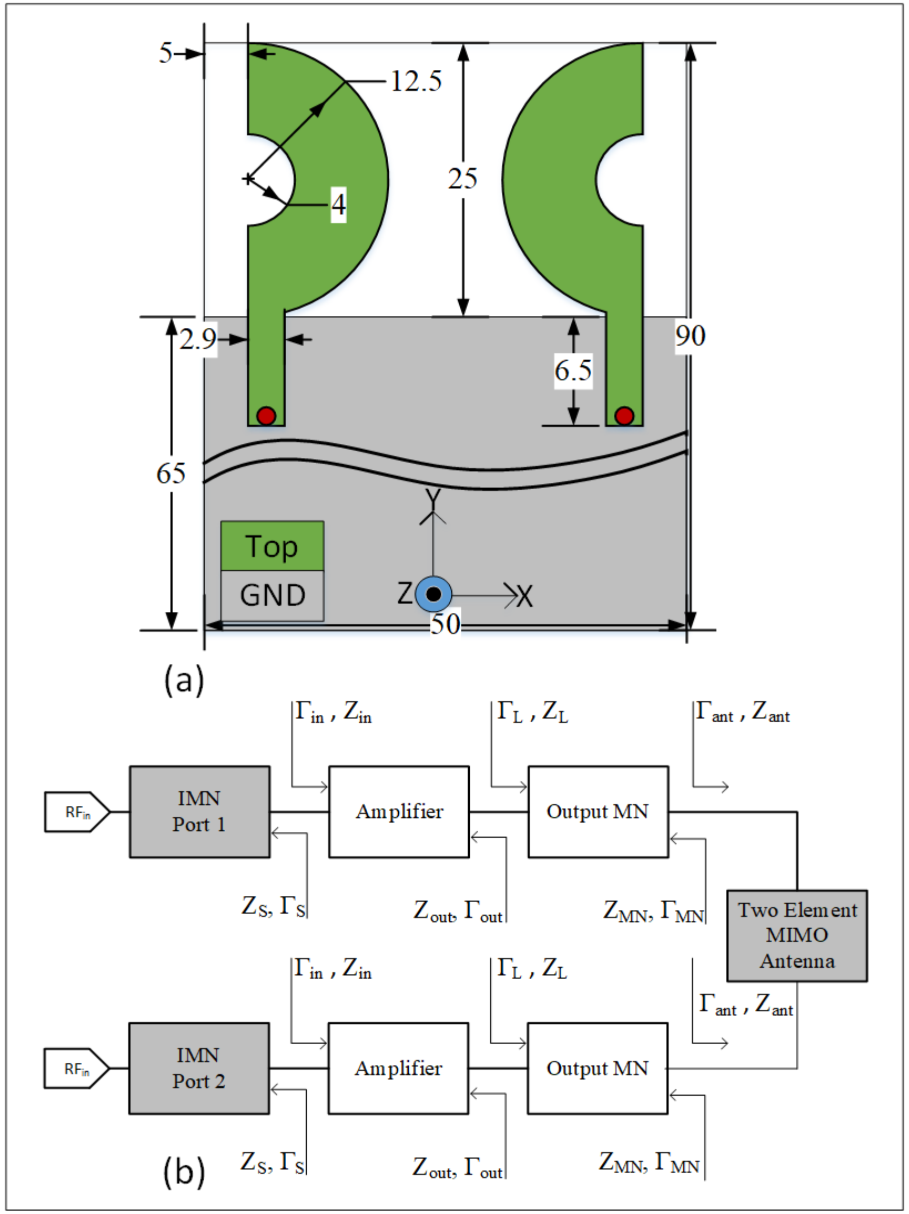


(a) (b)

(c) (d)

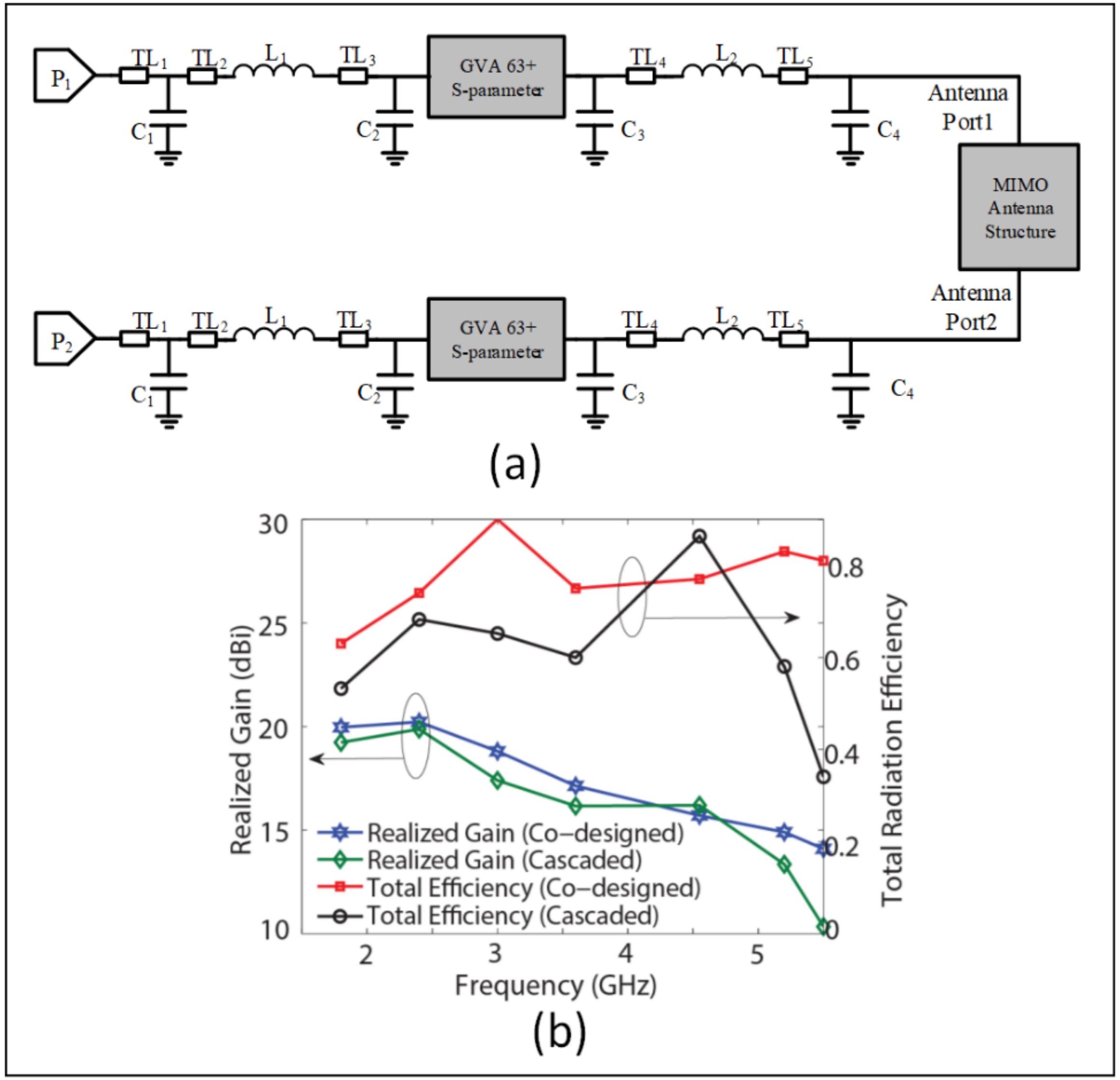


© 2019, **M. S. Sharawi**


5
12.5
4
25
90
2.9
6.5
65
Y
Top
GND
Z
X
50
Γ_{in} , Z_{in}
Γ_L , Z_L
Γ_{ant} , Z_{ant}
RF$_{in}$
IMN Port 1
Amplifier
Output MN
Z_S, Γ_S
Z_{out}, Γ_{out}
Z_{MN}, Γ_{MN}
Two Element MIMO Antenna
Γ_{in} , Z_{in}
Γ_L , Z_L
Γ_{ant} , Z_{ant}
RF$_{in}$
IMN Port 2
Amplifier
Output MN
Z_S, Γ_S
Z_{out}, Γ_{out}
Z_{MN}, Γ_{MN}

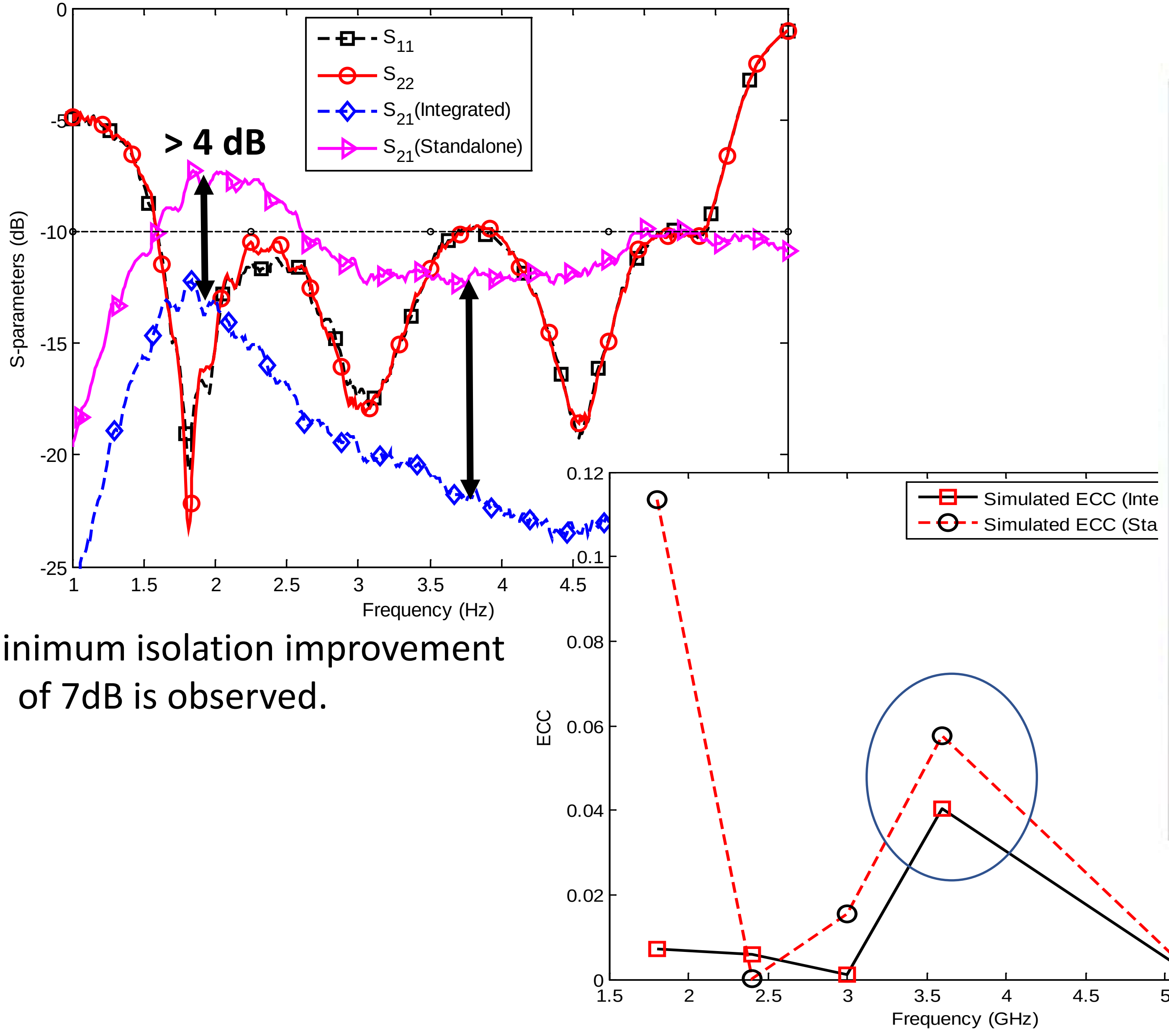
(a)

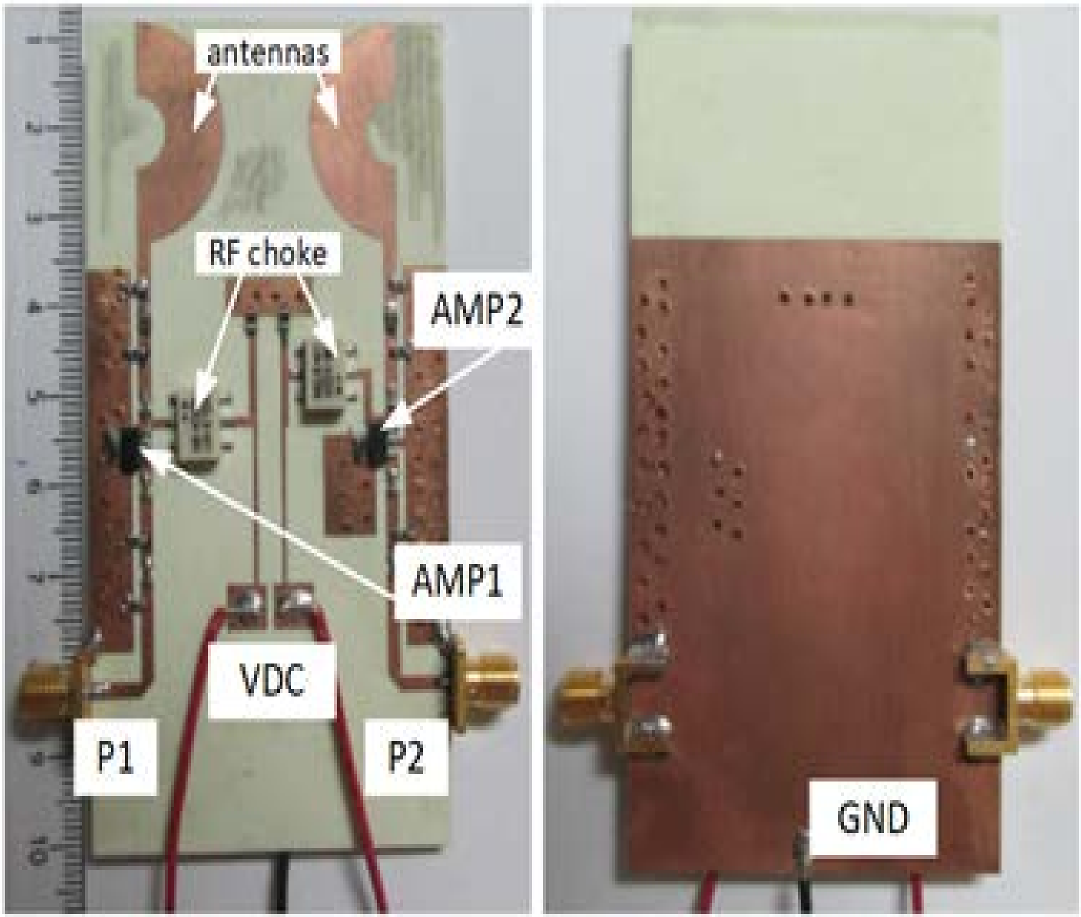
(b)


P_1
TL_1
TL_2
L_1
TL_3
GVA 63+ S-parameter
TL_4
L_2
TL_5
Antenna Port1
C_1
C_2
C_3
C_4
MIMO Antenna Structure
Antenna Port2
P_2
TL_1
TL_2
L_1
TL_3
GVA 63+ S-parameter
TL_4
L_2
TL_5
C_1
C_2
C_3
C_4
Realized Gain (dBi)
30
25
20
15
10
Total Radiation Efficiency
0.8
0.6
0.4
0.2
0
Frequency (GHz)
2
3
4
5
Realized Gain (Co−designed)
Realized Gain (Cascaded)
Total Efficiency (Co−designed)
Total Efficiency (Cascaded)

(a)

(b)




antennas
RF choke
AMP2
AMP1
VDC
P1
P2
GND

Minimum isolation improvement of 7dB is observed.

ECC is improved: less than 0.05

Potential challenges

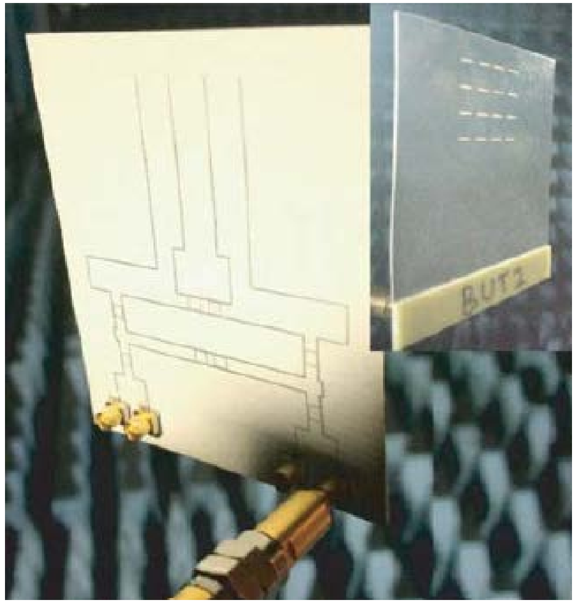
- Active integration needs further investigations in terms of tighter integration and co-design between the passive and active parts
- While a methodology was proven to provide better efficiency and integration compared to previous methods (as shown in previous slides), more cases needs to be tested within this methodology and add more to it (i.e. simultaneous Tx/Rx paths, MIMO with coupled elements, etc)
- Rely more on the active element feedback to realize wider bandwidth MN.
- Implement in more dense MIMO scenarios and aim for lower power consumption (i.e. Massive MIMO)
- Integration issues (device shape, hand gesture, radome, etc.)
- Coexistence with other antenna systems and bands
- What about mm-waves??

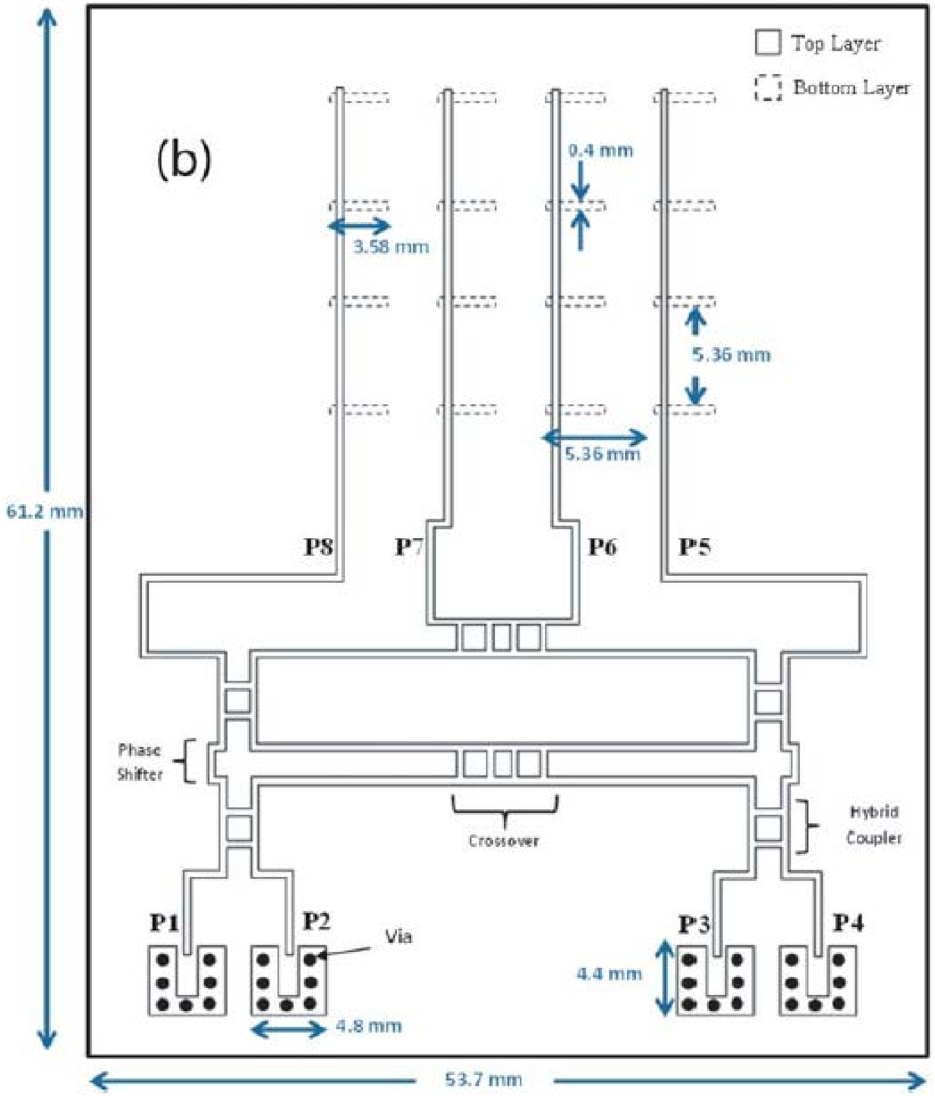
(C) mm-Wave MIMO Antenna Systems

Example 1:

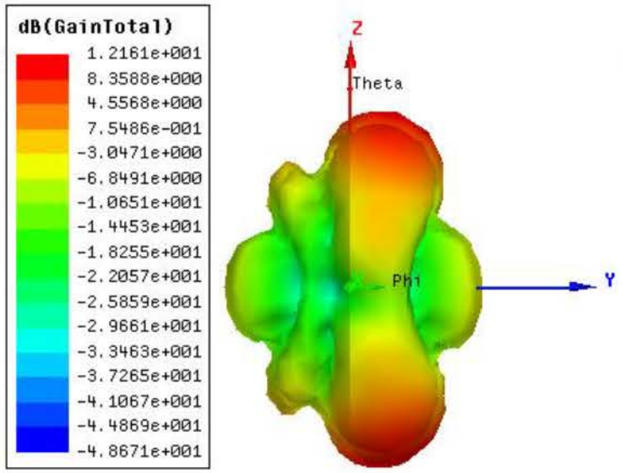
- Several major companies are considering the use of antenna arrays at 28-38 GHz for short range mm-wave links for 5G
- My group started investigating mm-wave antennas for 5G in collaboration with U-Michigan and RMC (Canada) early on (back in 2014).

4x4 slot array @ 28.5 GHz
with Butler Matrix on
0.13mm substrate
And 1GHz BW

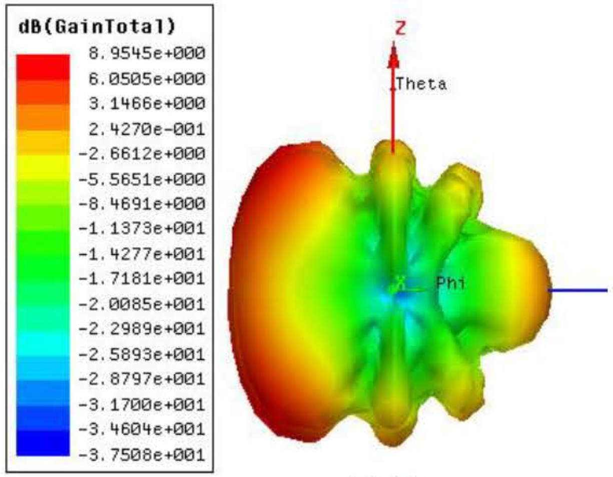



Top Layer
Bottom Layer
(b)
0.4 mm
3.58 mm
5.36 mm
5.36 mm
61.2 mm
P8
P7
P6
P5
Phase Shifter
Crossover
Hybrid Coupler
P1
P2
Via
P3
P4
4.4 mm
4.8 mm
53.7 mm

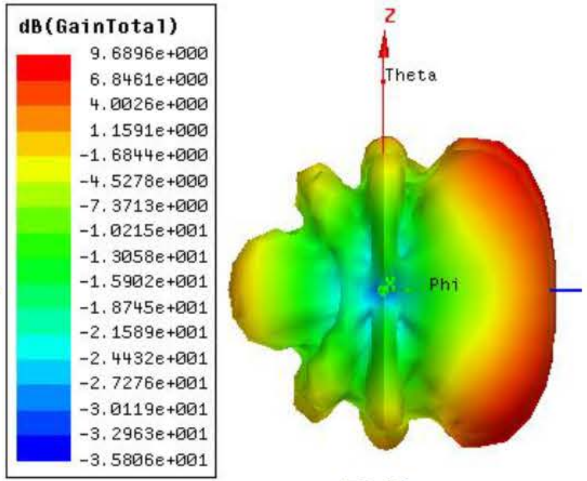
[13] A.T. Al-Reshaid, **M. S. Sharawi,** S. Podilchak and K. Sarabandi, "Compact Millimeter-Wave Switched Beam Antenna Arrays for Short Range Communications," Microwave and Optical Technology Letters, Wiley, Vol. 58, No. 8, pp. 1917-1921, August 2016.



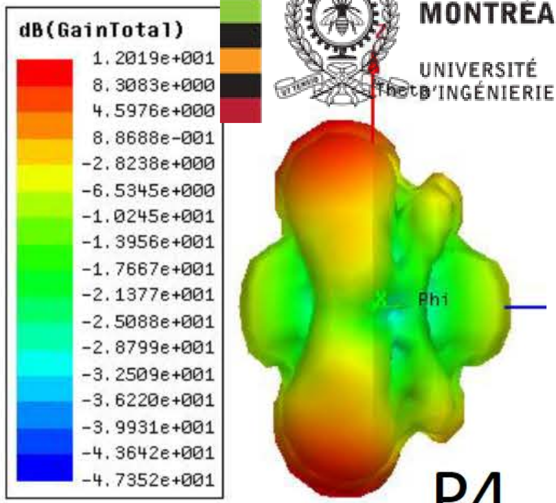
P1



P2

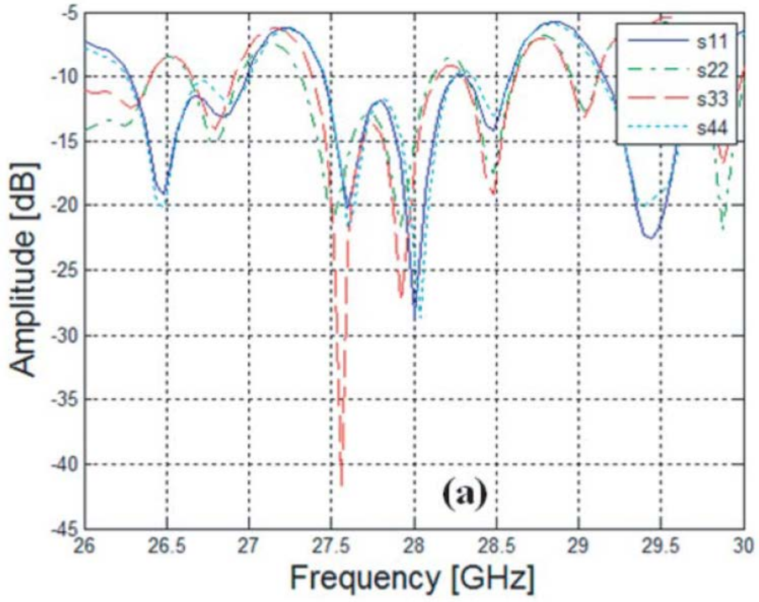


P3

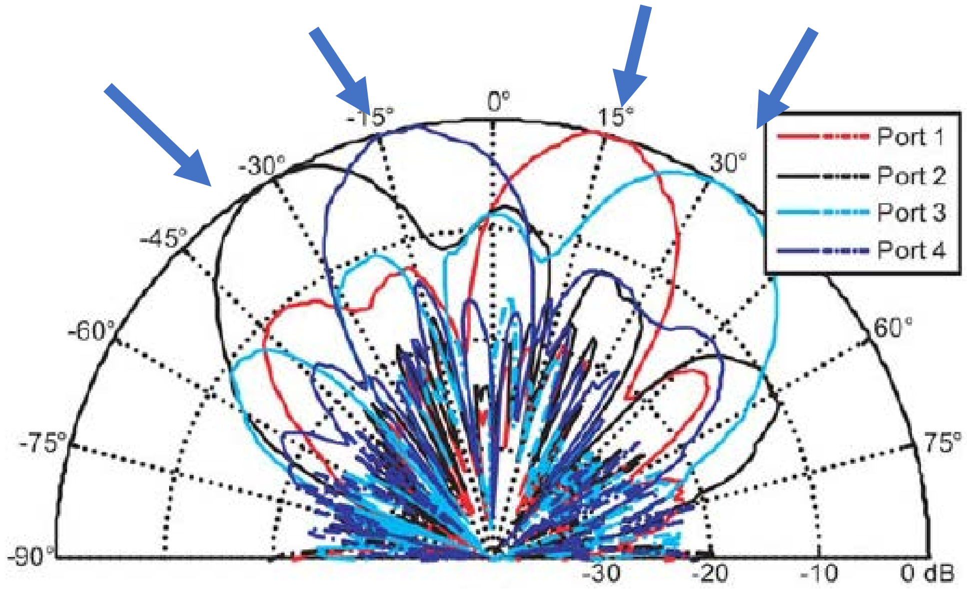


P4

@ 28.5 GHz



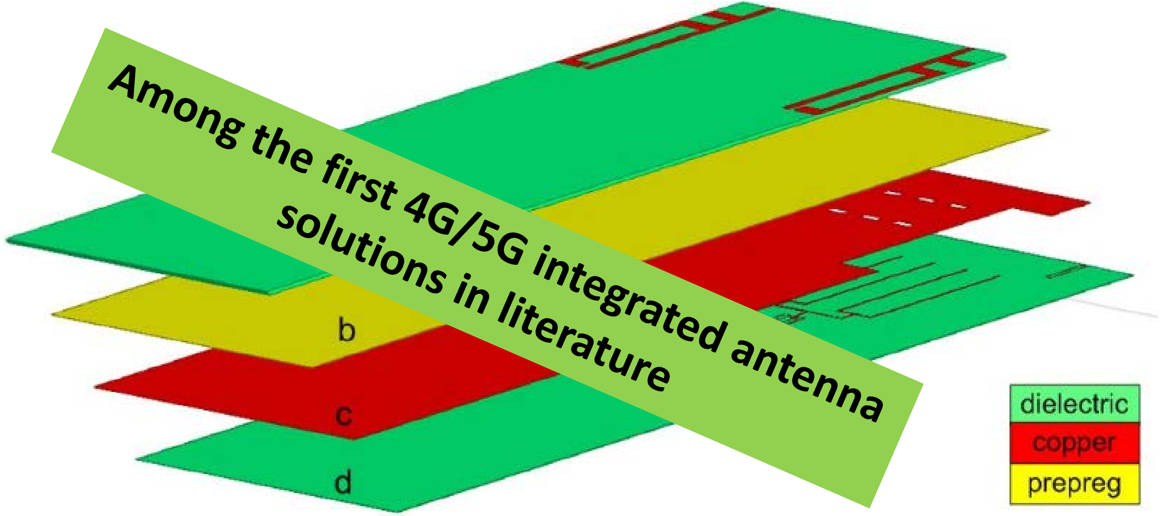
Measured S-parameters



Measured Gain Patterns

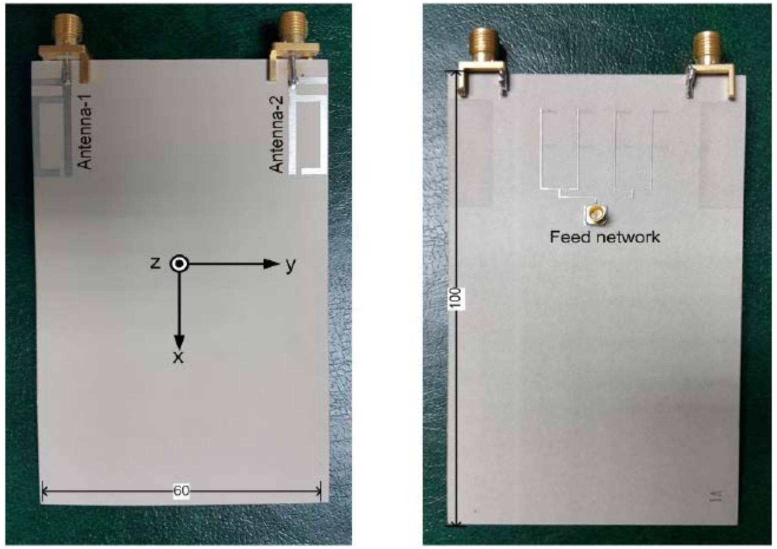
Example 2:

Integrated 4G MIMO / 5G mm-wave array Antenna (1.87-2.48 GHz) & (26 – 28.4 GHz)

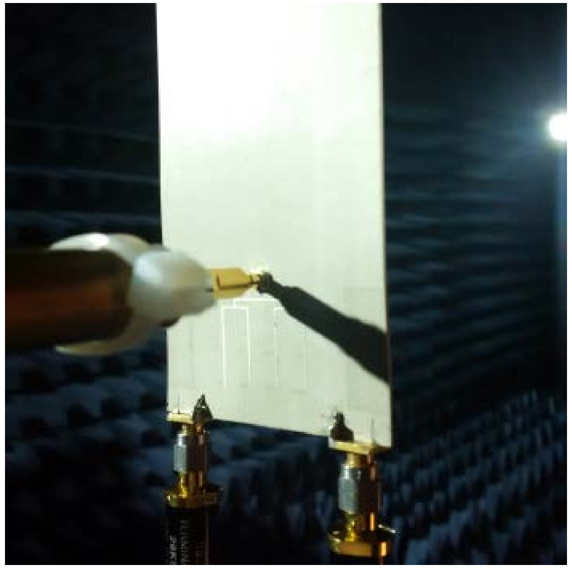

b
c
d
dielectric
copper
prepreg

Among the first 4G/5G integrated antenna solutions in literature

- Top Layer (RO3003, thickness = 0.76mm)
  - ➔ Holding MIMO 4G Antennas
- Ground Layer
- Bonding Material (ε_r = 2.94, thickness = 0.05mm)
- Bottom Layer (RO3003, thickness = 0.13mm)
  - ➔ Holding mm-wave slot antenna array feed network

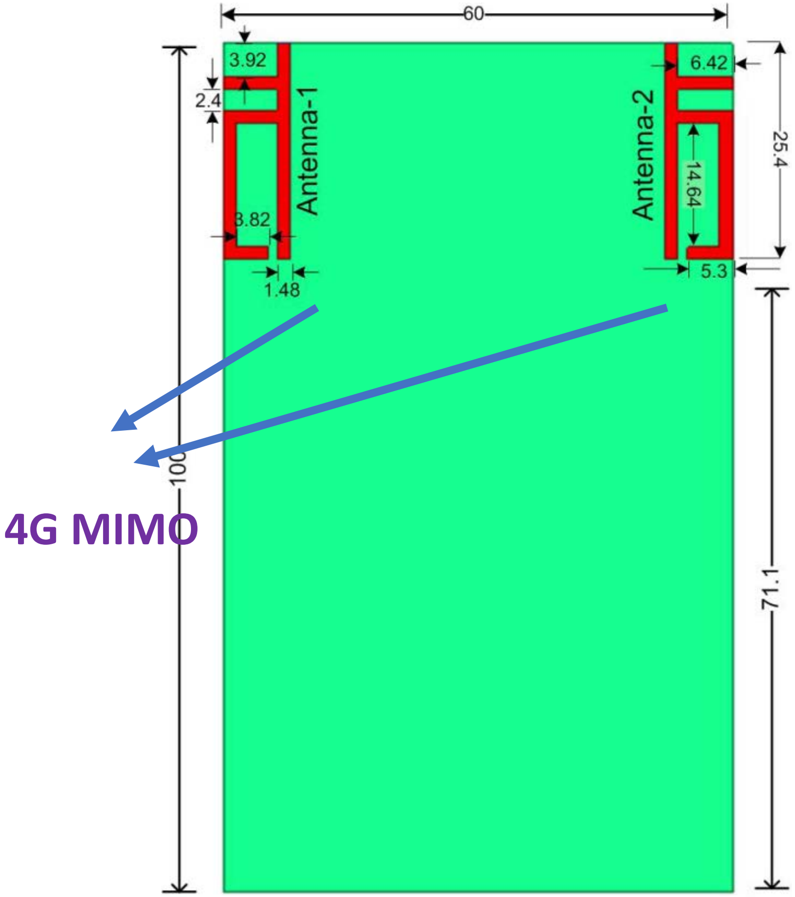

Antenna-1
Antenna-2
z
y
x
60
Feed network
100

@28GHz, 8dBi gain

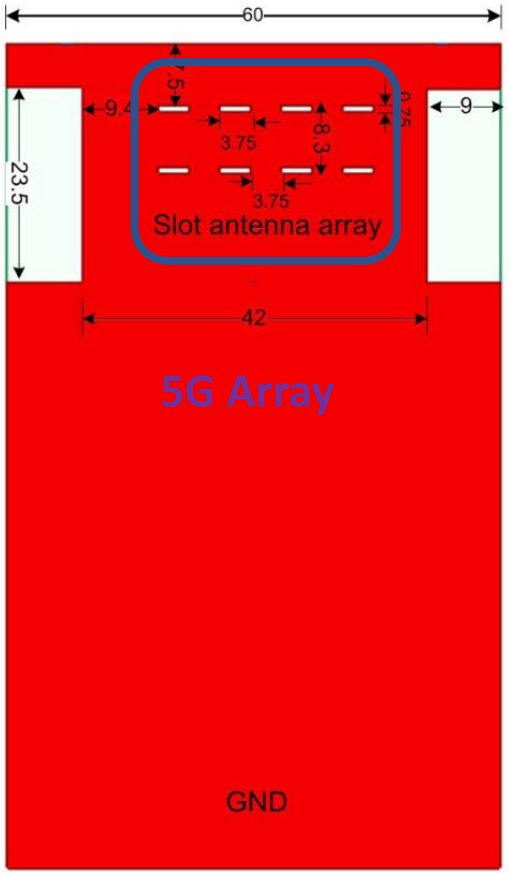


[14] R. Hussain, A. Al-Reshaid, S. K. Podilchak and **M. S. Sharawi**, “Compact 4G MIMO antenna integrated with a 5G array for current and future mobile handsets,” IET Microwaves, Antennas and Propagation Vol. 11, No. 2, pp. 271-279, 2017.

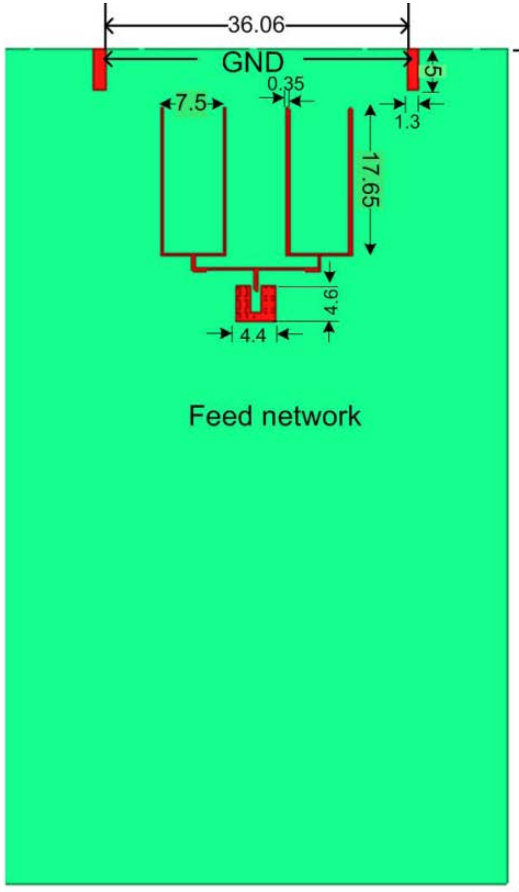
*All dimensions are in millimeters (mm)


60
3.92
2.4
Antenna-1
3.82
1.48
6.42
Antenna-2
14.64
25.4
5.3
71.1
100
4G MIMO

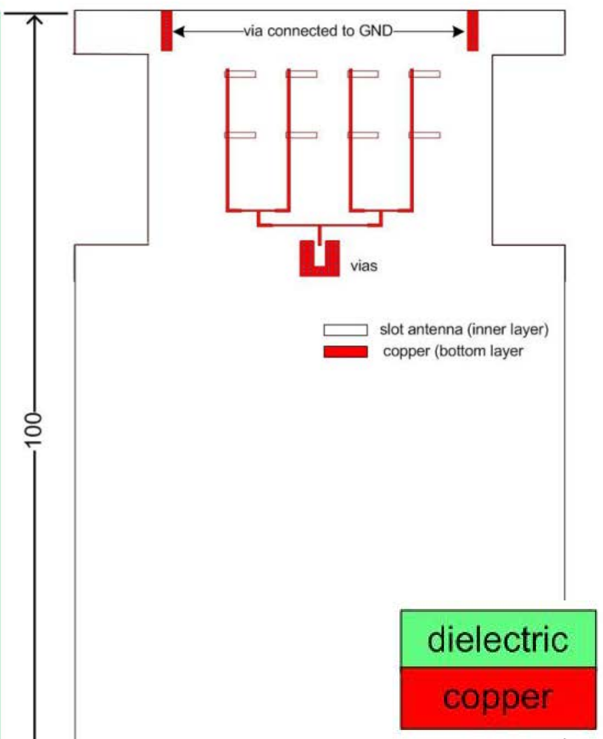
2-element MIMO antenna


60
7.5
9.4
3.75
8.3
0.75
9
3.75
23.5
Slot antenna array
42
5G Array
GND

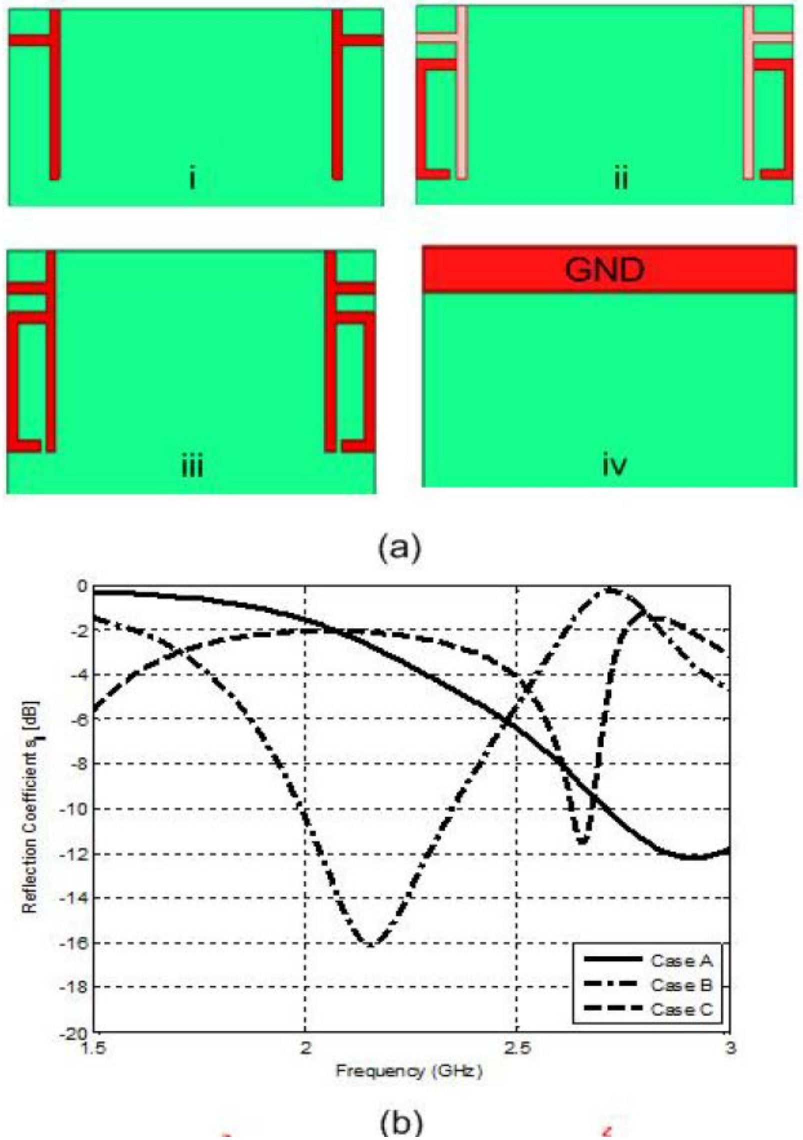
GND layer with mm-wave slot antenna array


36.06
GND
5
0.35
7.5
1.3
17.65
4.6
4.4
Feed network

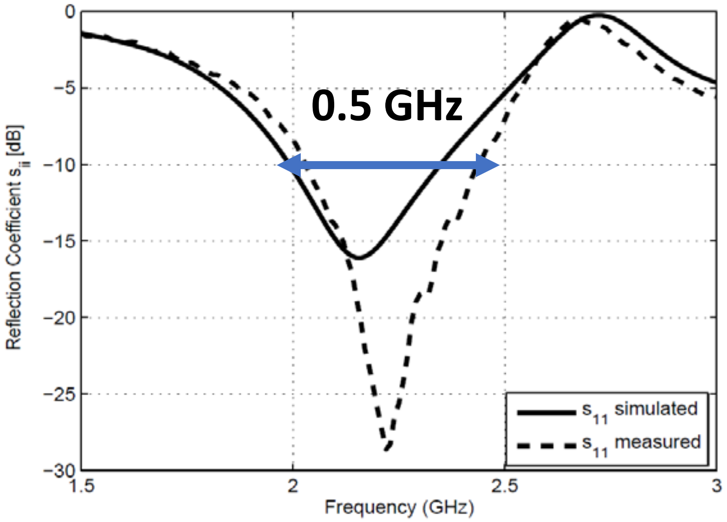
mm-wave feed network


via connected to GND
vias
slot antenna (inner layer)
copper (bottom layer
100
dielectric
copper

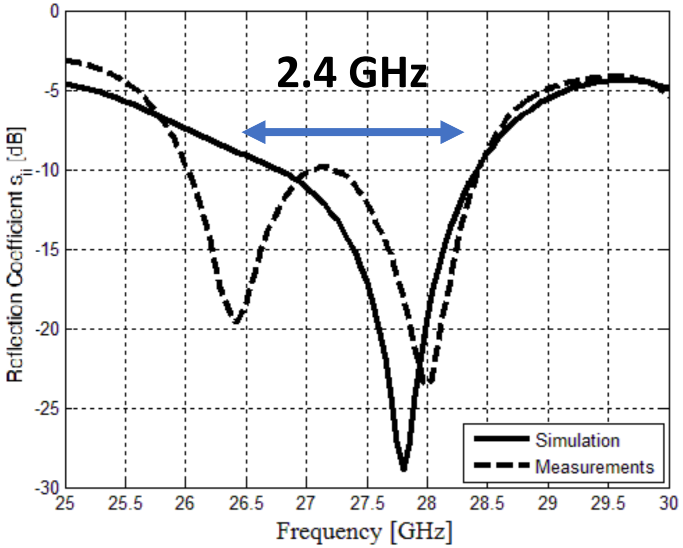
mm-wave slot antenna with feeding network



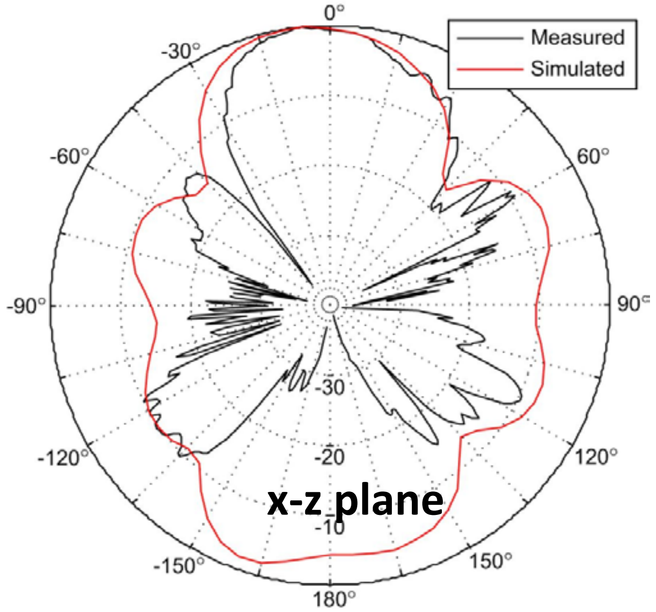
Evolution of the 4G antenna



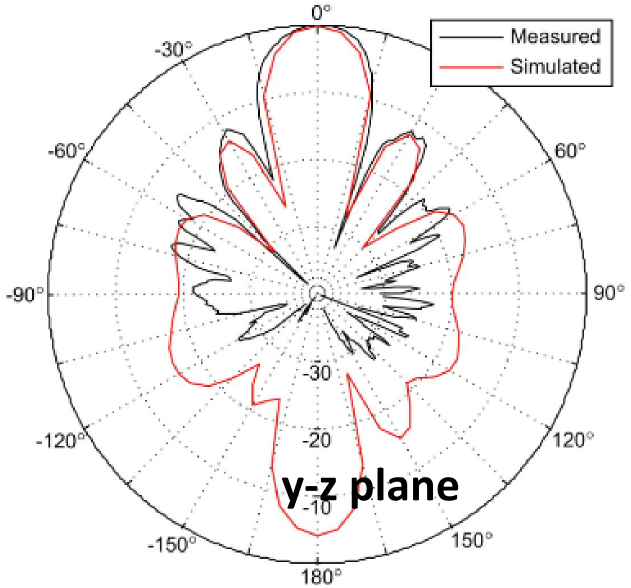
Reflection coefficients of the MIMO antenna



Reflection coefficients of the mm-wave antenna array



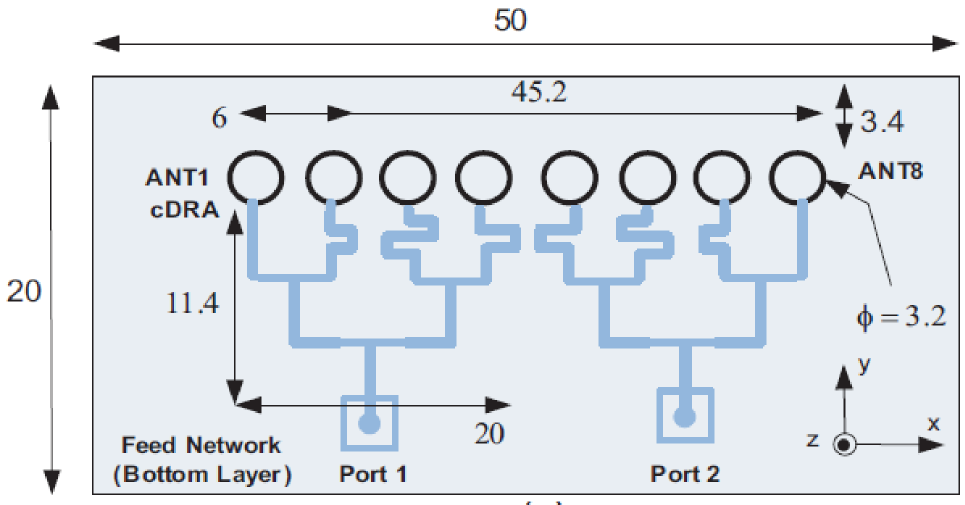
x-z plane



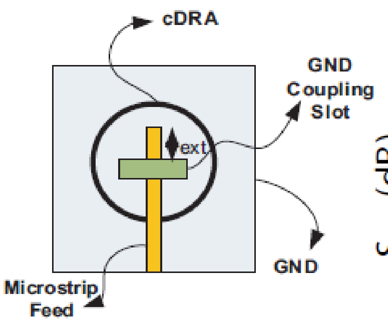
y-z plane

Example 3:

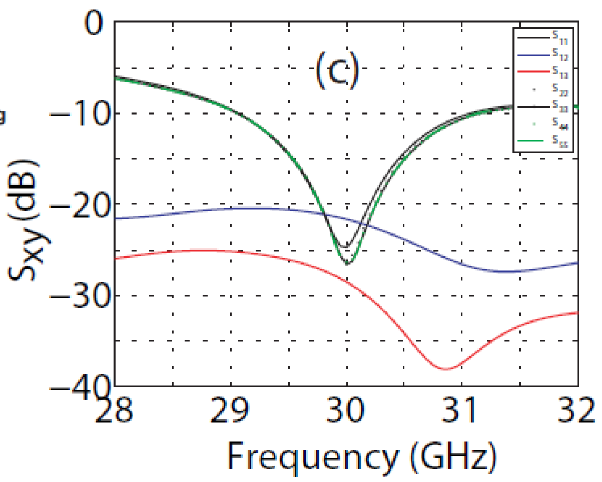
mm-wave cDRA MIMO (29.5 – 31 GHz) w/switched beams

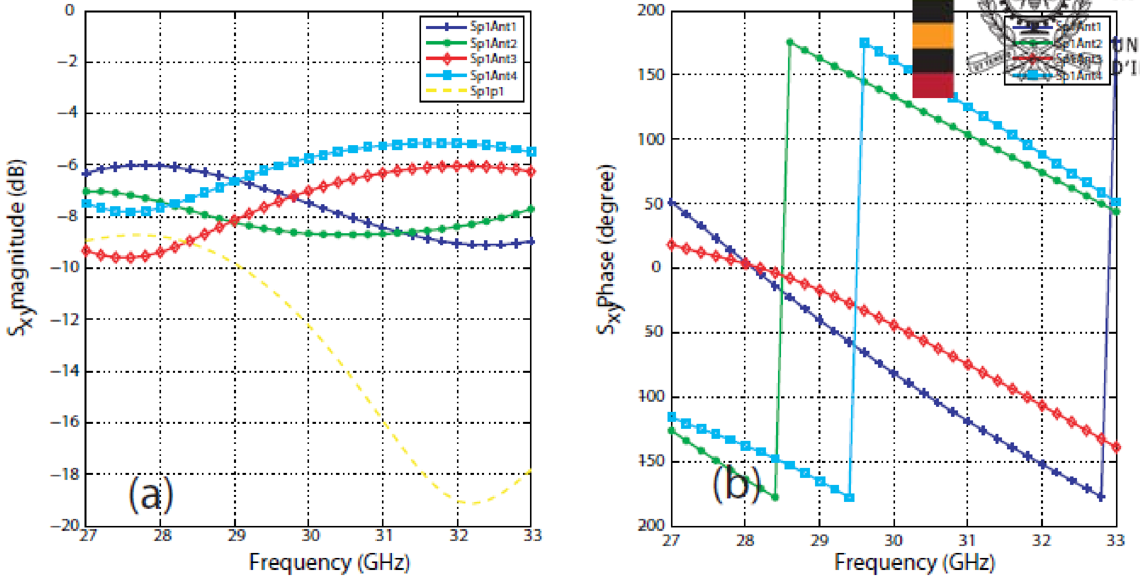

50
45.2
6
3.4
20
ANT1
cDRA
ANT8
11.4
ϕ = 3.2
y
x
z
20
Feed Network
(Bottom Layer)
Port 1
Port 2

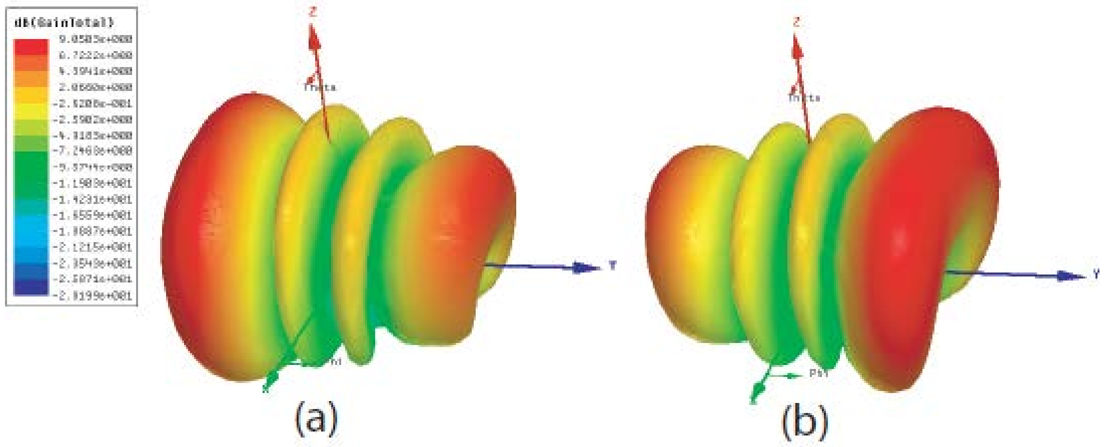
(a)


cDRA
GND
Coupling
Slot
ext
GND
Microstrip
Feed

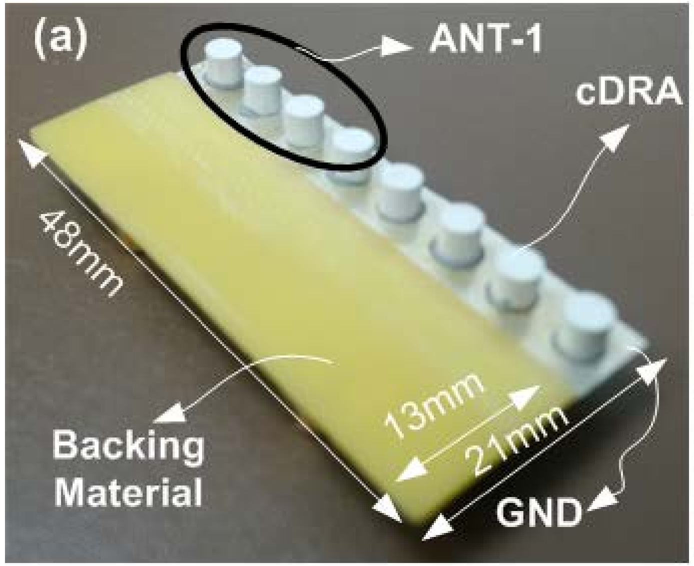
(b)

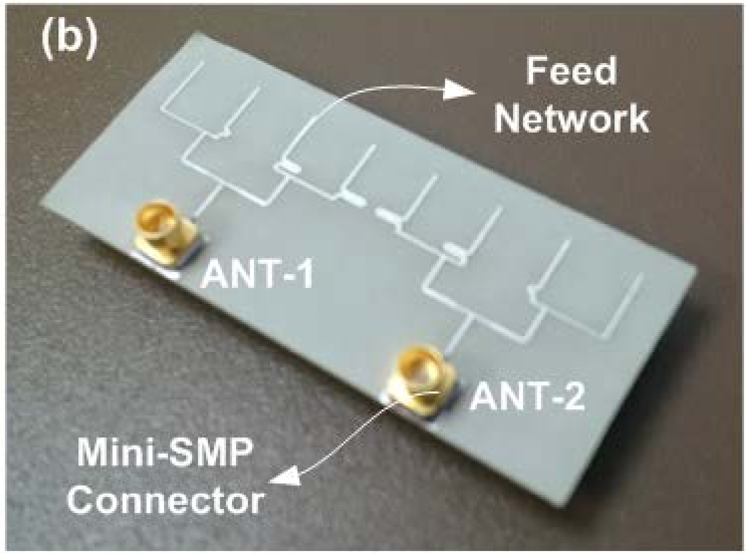




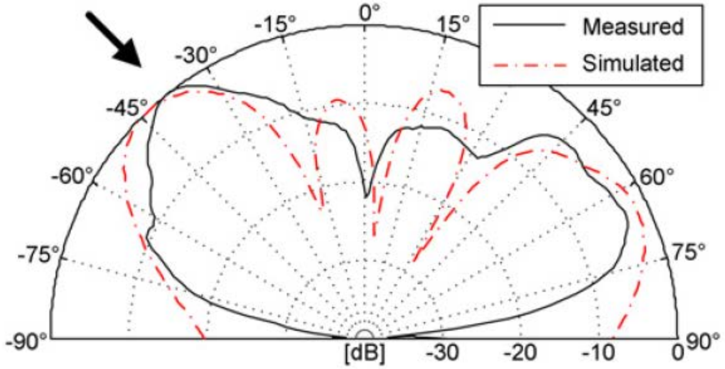

dB(GainTotal)
9.0583e+000
6.7222e+000
4.3941e+000
2.0660e+000
-2.6208e-001
-2.5902e+000
-4.9183e+000
-7.2463e+000
-9.5744e+000
-1.1903e+001
-1.4231e+001
-1.6559e+001
-1.8887e+001
-2.1215e+001
-2.3543e+001
-2.5871e+001
-2.8199e+001
Z
Theta
Y
Phi
(a)
(b)

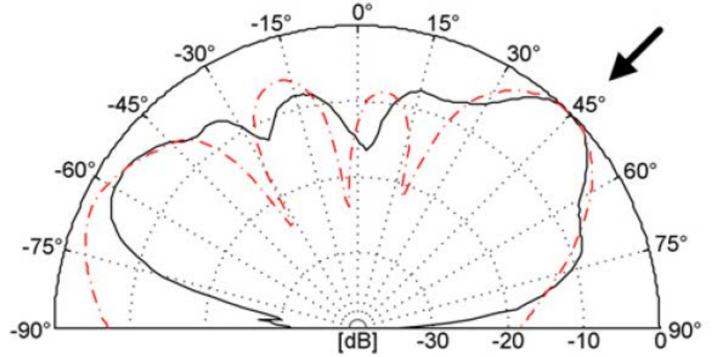
[15] **M. S. Sharawi**, S. K. Podilchak, M. T.Hussain and Y. M. M. Antar, “Dielectric Resonator Based MIMO Antenna System Enabling mm-wave Mobile Devices,” IET Microwaves, Antennas, And Propagation Vol. 11, No. 2, pp. 287-293, 2017.

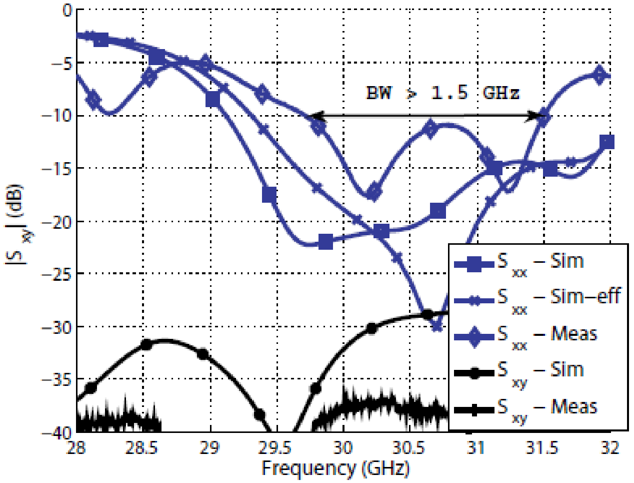

(a)
ANT-1
cDRA
48mm
Backing
Material
13mm
21mm
GND

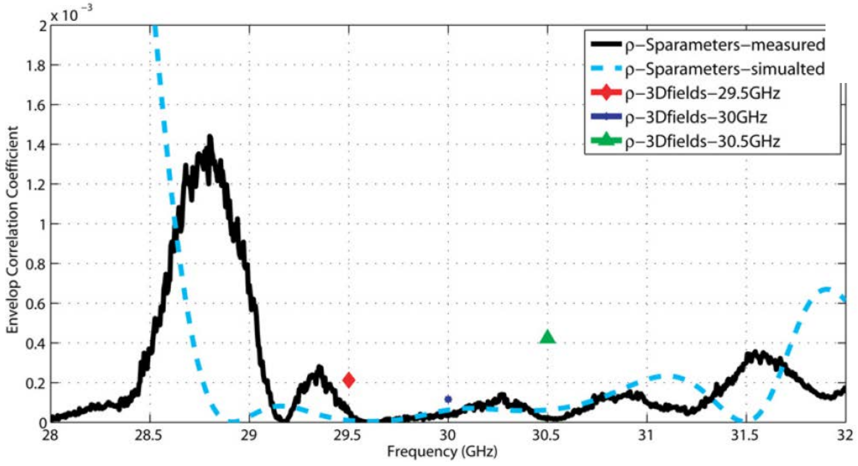

(b)
Feed
Network
ANT-1
ANT-2
Mini-SMP
Connector

- **Gain patterns at 30 GHz**
- **8dBi gain**
- **ECC values are very low due to separated beam directions**



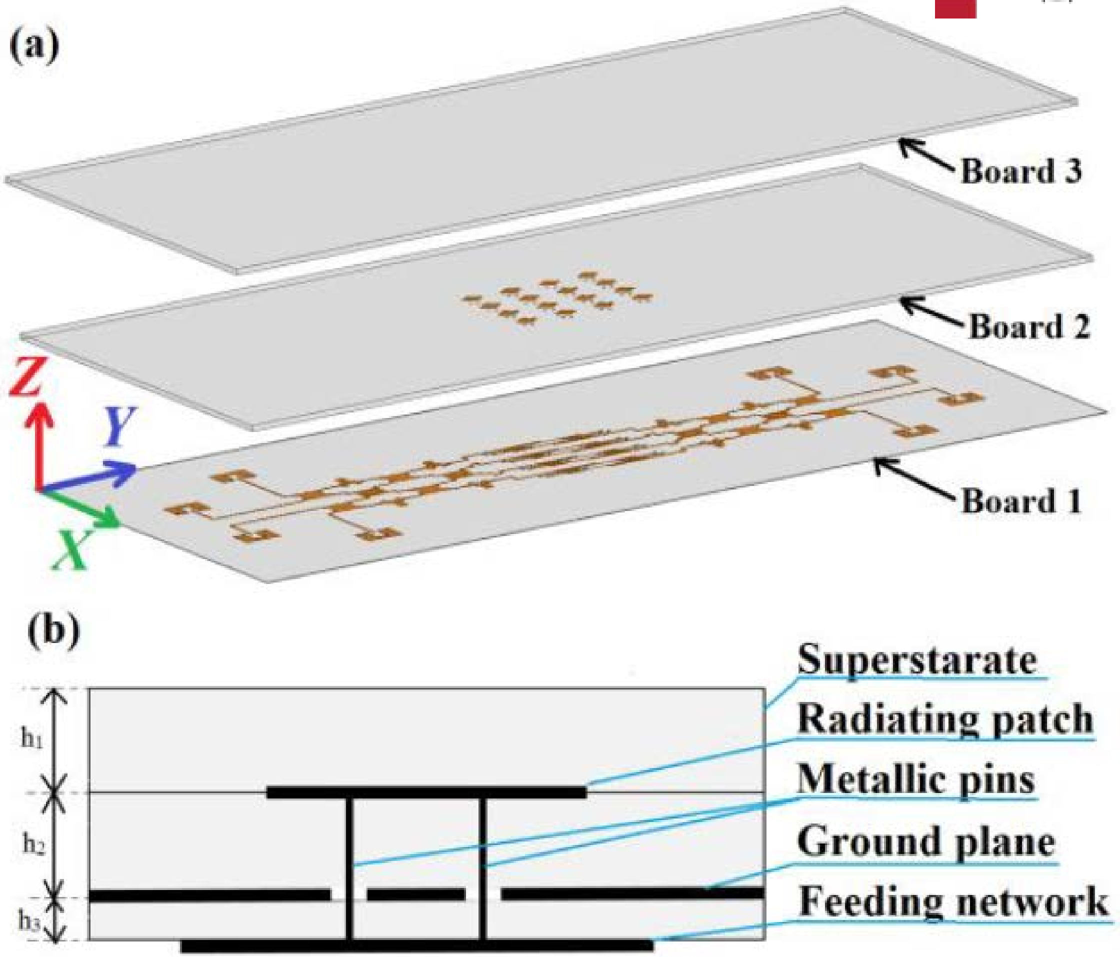






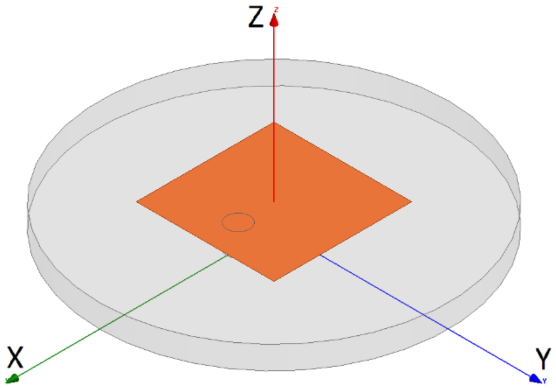
Example 4:

- Dual-polarized Switched-Beam Planar Antenna Array for 5G access points and small form factor applications
- 5G 26-31.4 GHz→ BW = 5.4 GHz
- Covering NR bands of 26.5-29.5 GHz and 27.5-28.35 GHz
- Wideband dual-polarized planar Butler-Matrix design
- Simple multi-layer structure
- +/- 42^o beam switching using a 16-element planar dual-polarized patch array

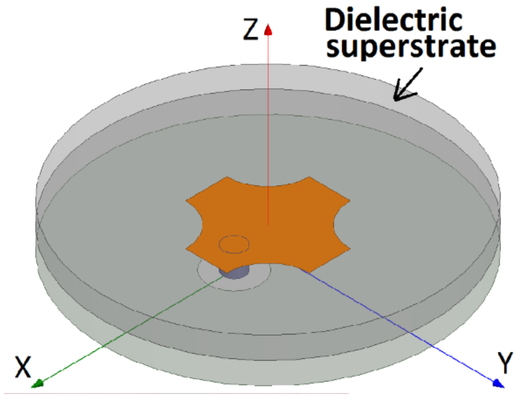

(a)
Board 3
Board 2
Board 1
Z
Y
X
(b)
h1
h2
h3
Superstarate
Radiating patch
Metallic pins
Ground plane
Feeding network

[16] K. Klionovski, **M. S. Sharawi** and A. Shamim, “A Dual-Polarization Switched-Beam Patch Antenna Array for Millimeter-Wave Applications,” IEEE Transactions on Antennas and Propagation, Vol. 67, No. 5, pp. 3510-3515, May 2019.

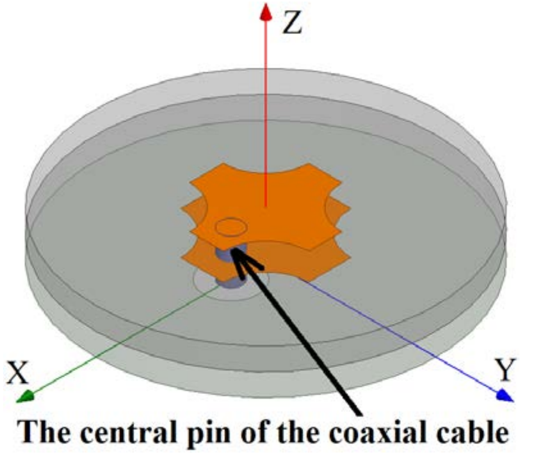
Rectangular Patch Antenna Design



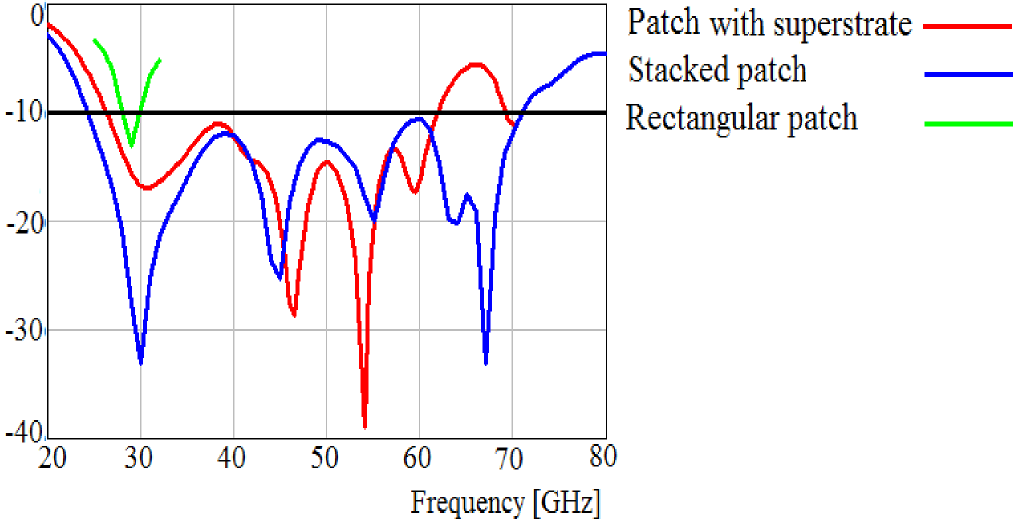
Wide-Band Patch Antenna Design with Superstrate


Z
Dielectric superstrate
X
Y

Wide-Band Stacked Patch Antenna Design

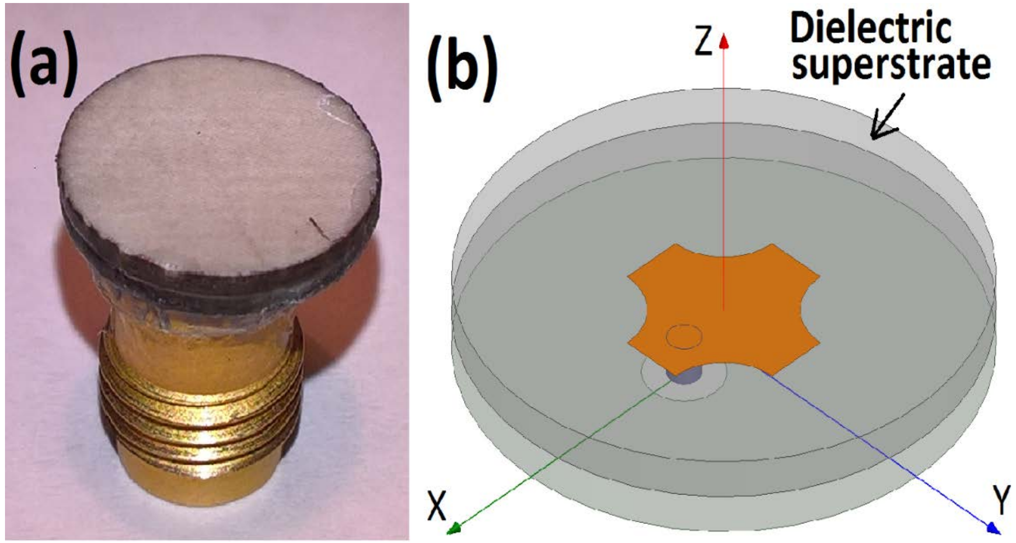

Z
X
Y
The central pin of the coaxial cable

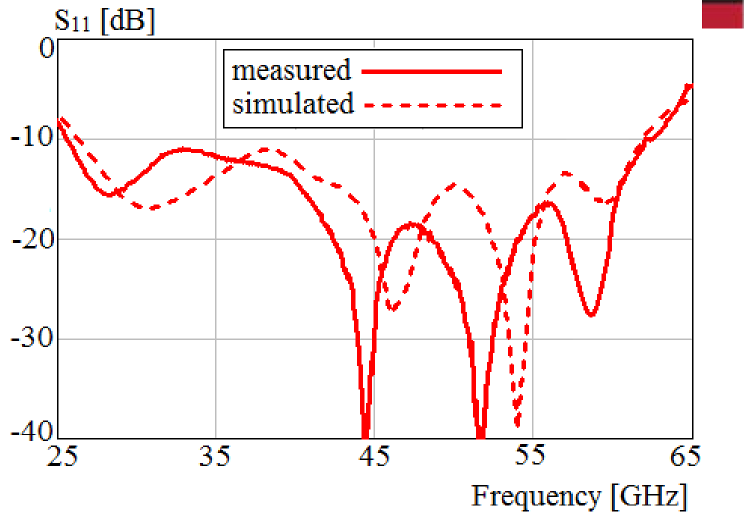
- A combination of special cut-outs in patch and dielectric superstrate or stacked design ensure Wide BW
- As compared with 5% BW of a rectangular patch, 84% and 100% BW were achieved for the patch design with superstrate and the stacked patch design

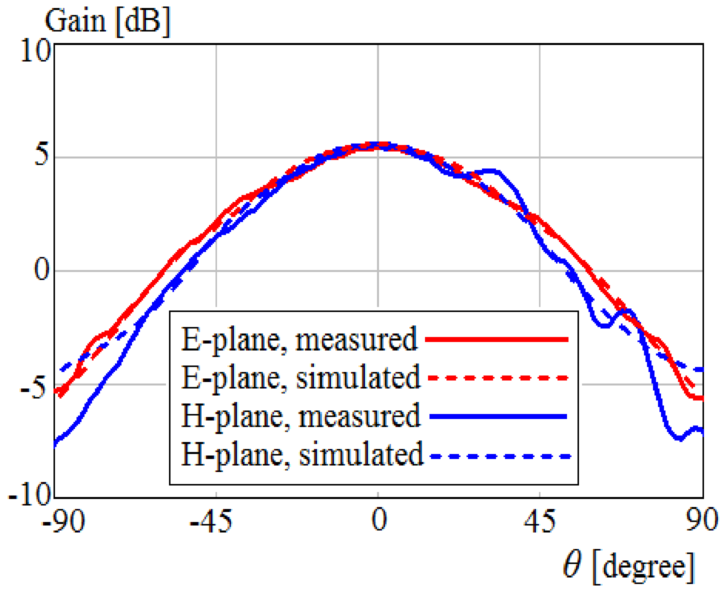


[17] K. Klionovsky and A. Shamim, “Physically Connected Stacked Patch Antenna Design With 100% Bandwidth,” IEEE Antennas and Wireless Propagation Letters, Vol. 2016, pp. 3208-3211, 2016.

Wide-Band Patch Antenna Design with Superstrate


(a)
(b)
Z
Dielectric superstrate
X
Y



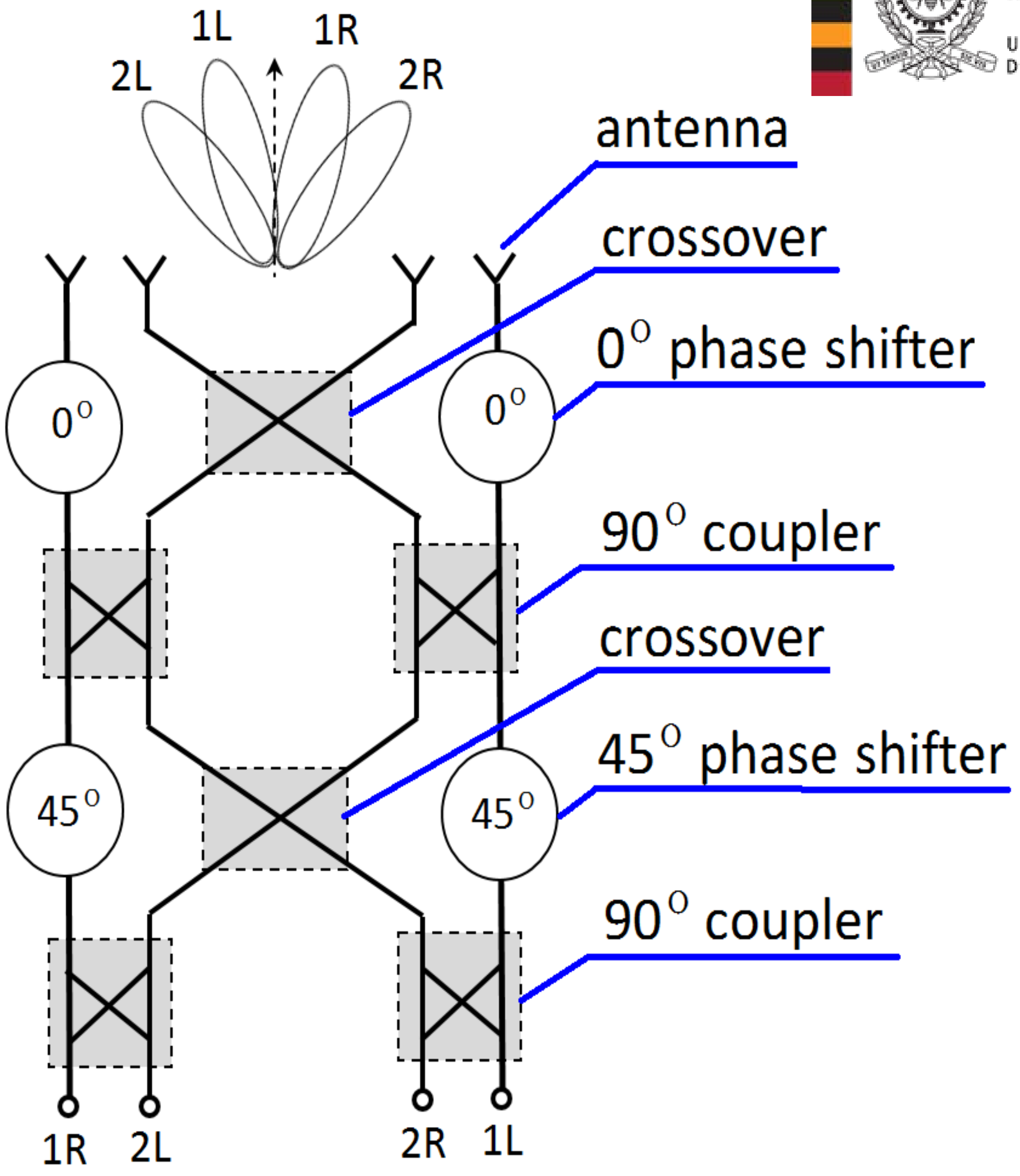


- Built prototype preforms well, matched for the band of 25-62 GHz
- decent gain 5dB
- broad radiation pattern (±45˚ for 3dB level)

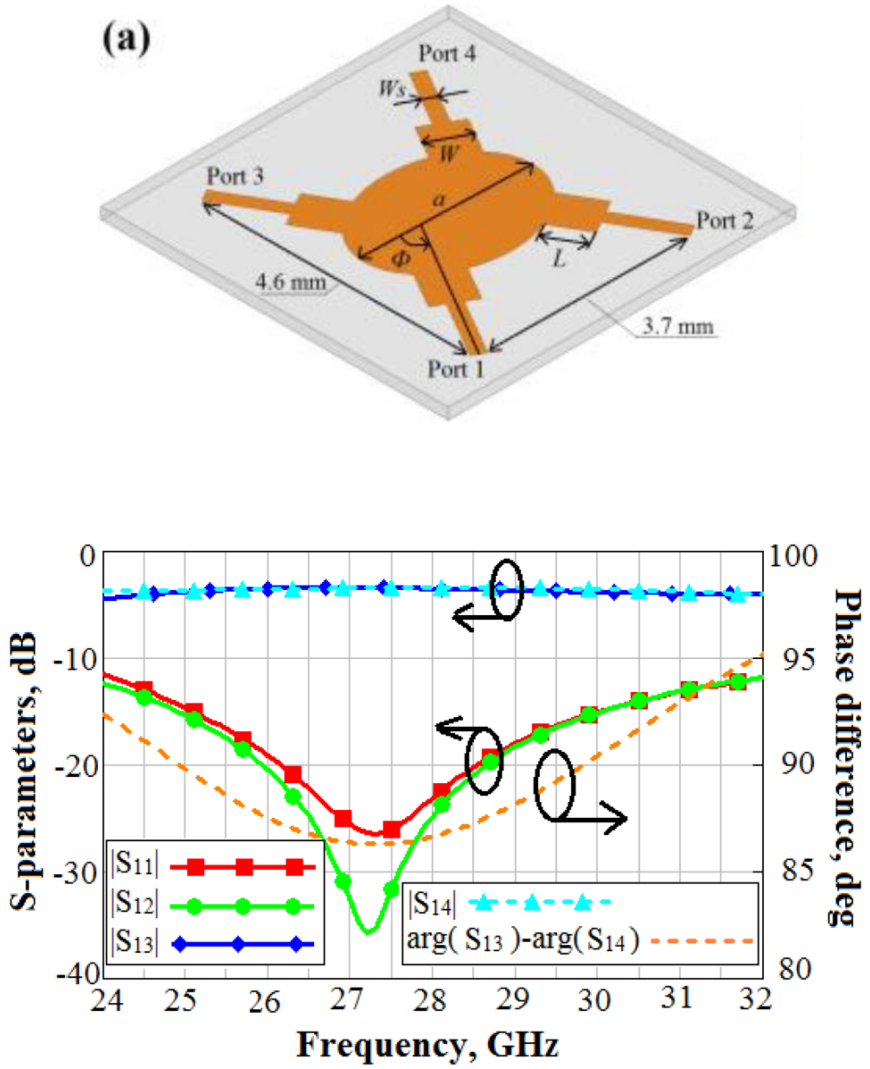
A standard scheme of the Butler matrix contains:

1. Four 3-dB directional couplers
2. Two 0˚ and 45˚ phase shifters
3. Two crossovers

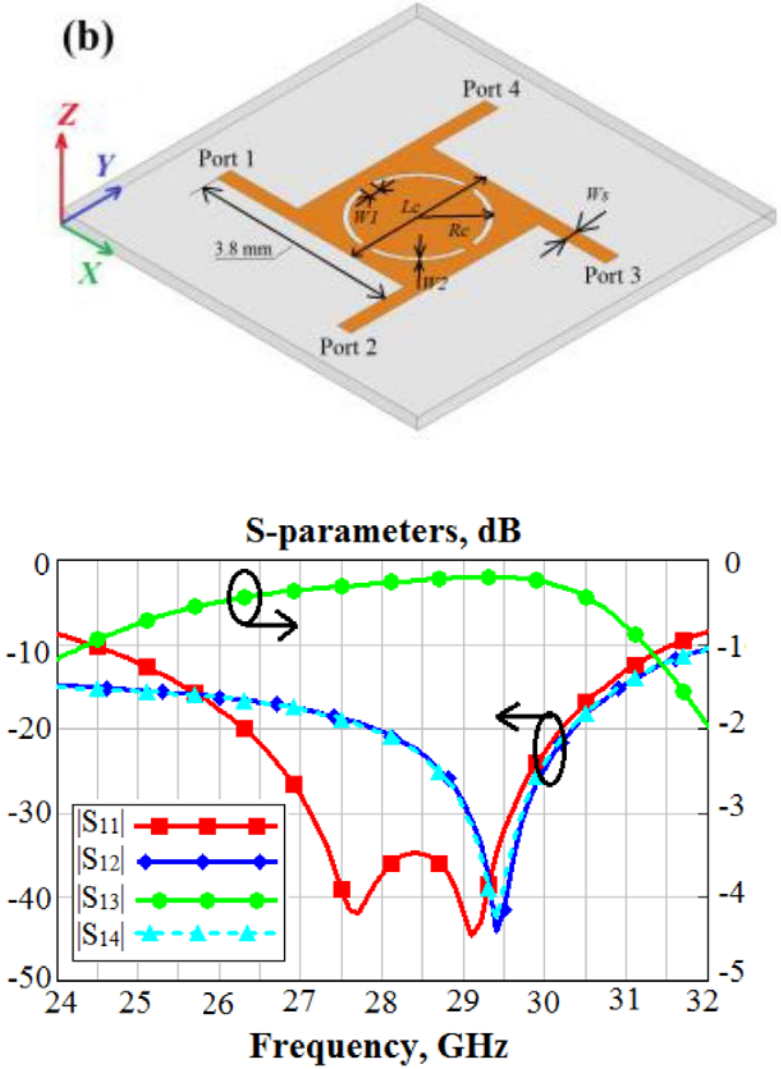
When port 1R, 2L, 2R or 1L is excited, we have equal amplitude distribution at antennas, and linear phase distribution with 90˚ phase shift between the neighbor antennas


1L
1R
2L
2R
antenna
crossover
0^{O} phase shifter
0^{O}
0^{O}
90^{O} coupler
crossover
45^{O} phase shifter
45^{O}
45^{O}
90^{O} coupler
1R
2L
2R
1L

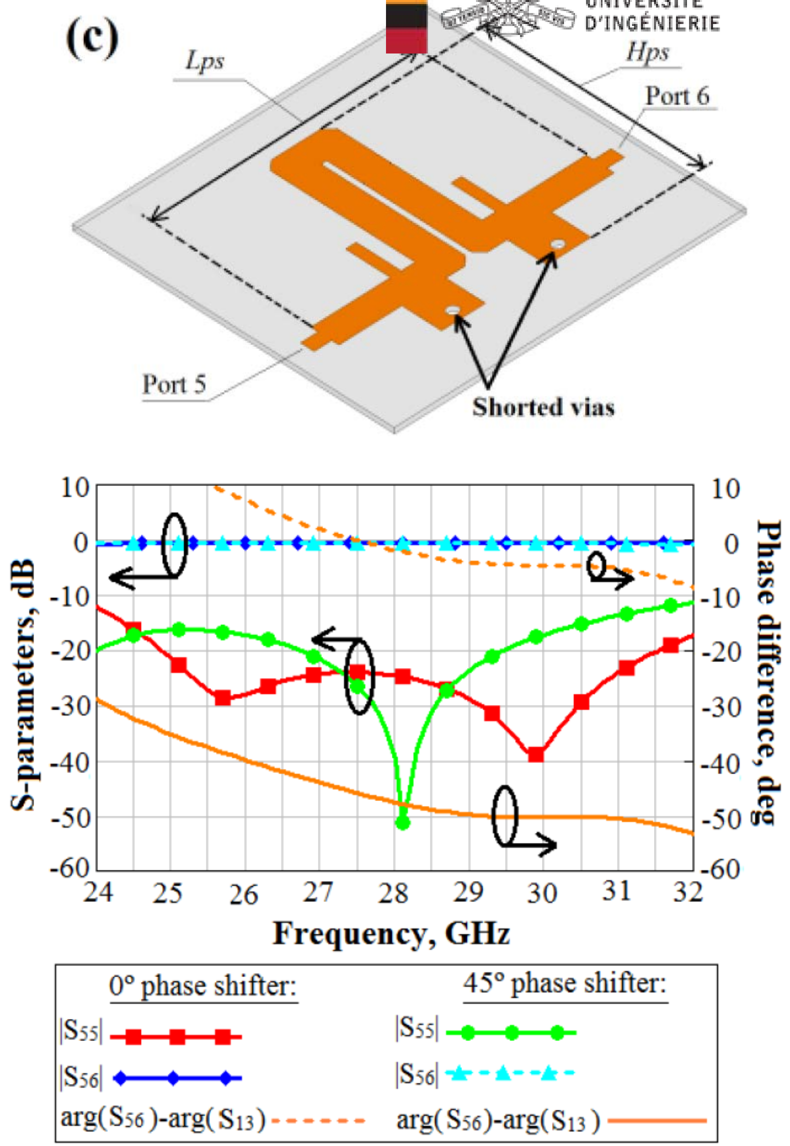
The scheme of a 4-beams Butler matrix



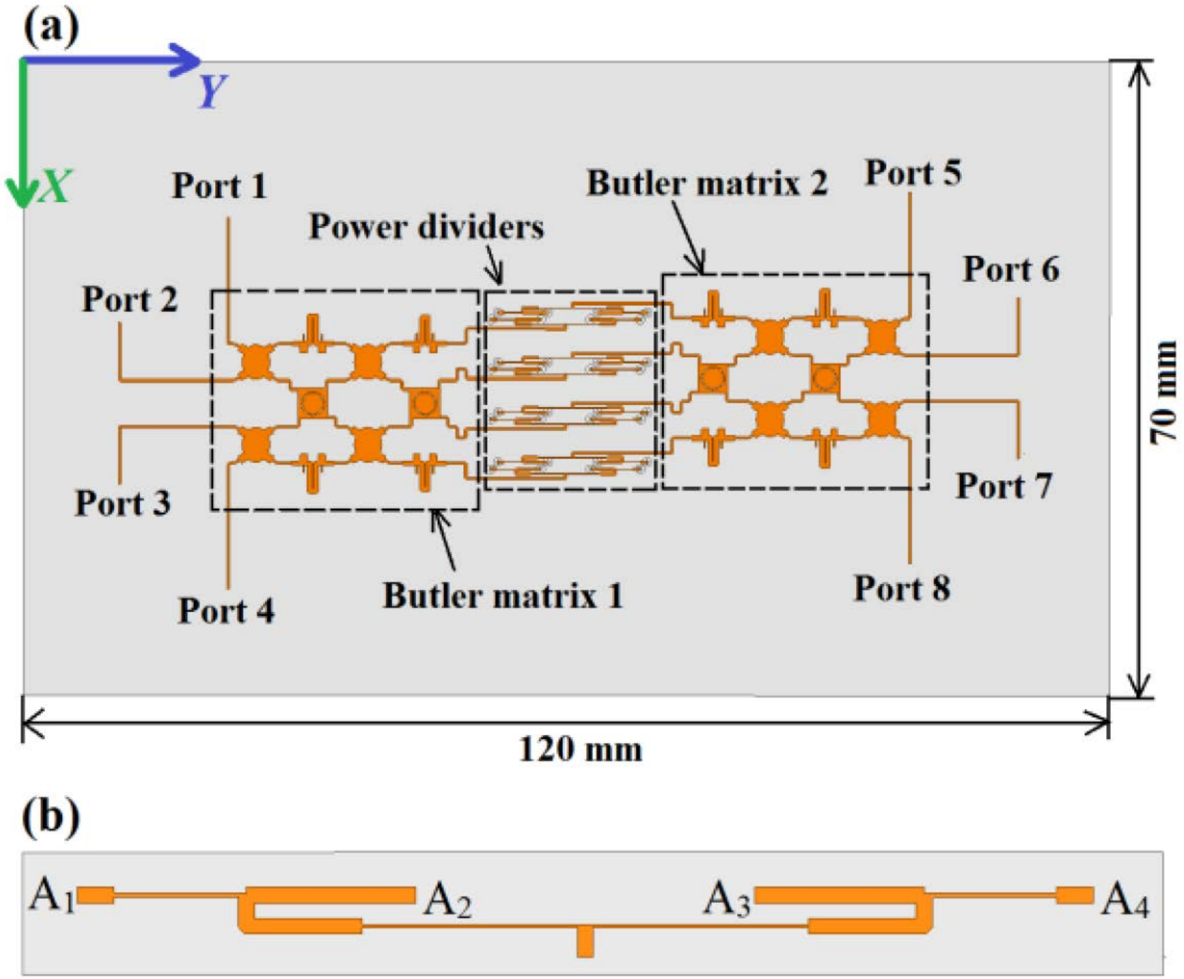
Wide-band coupler



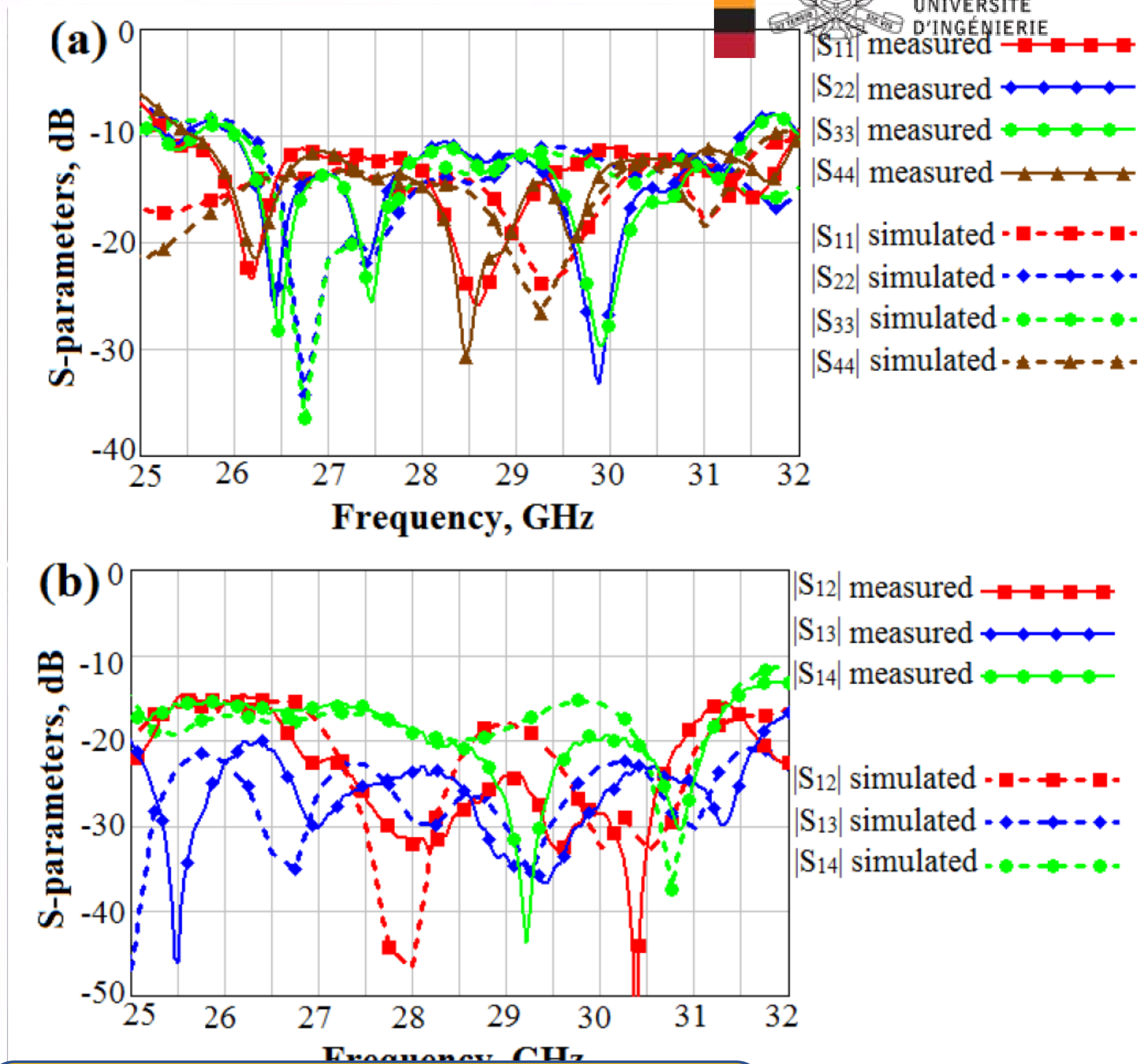
Wide-band cross-over



Wide-band shifter

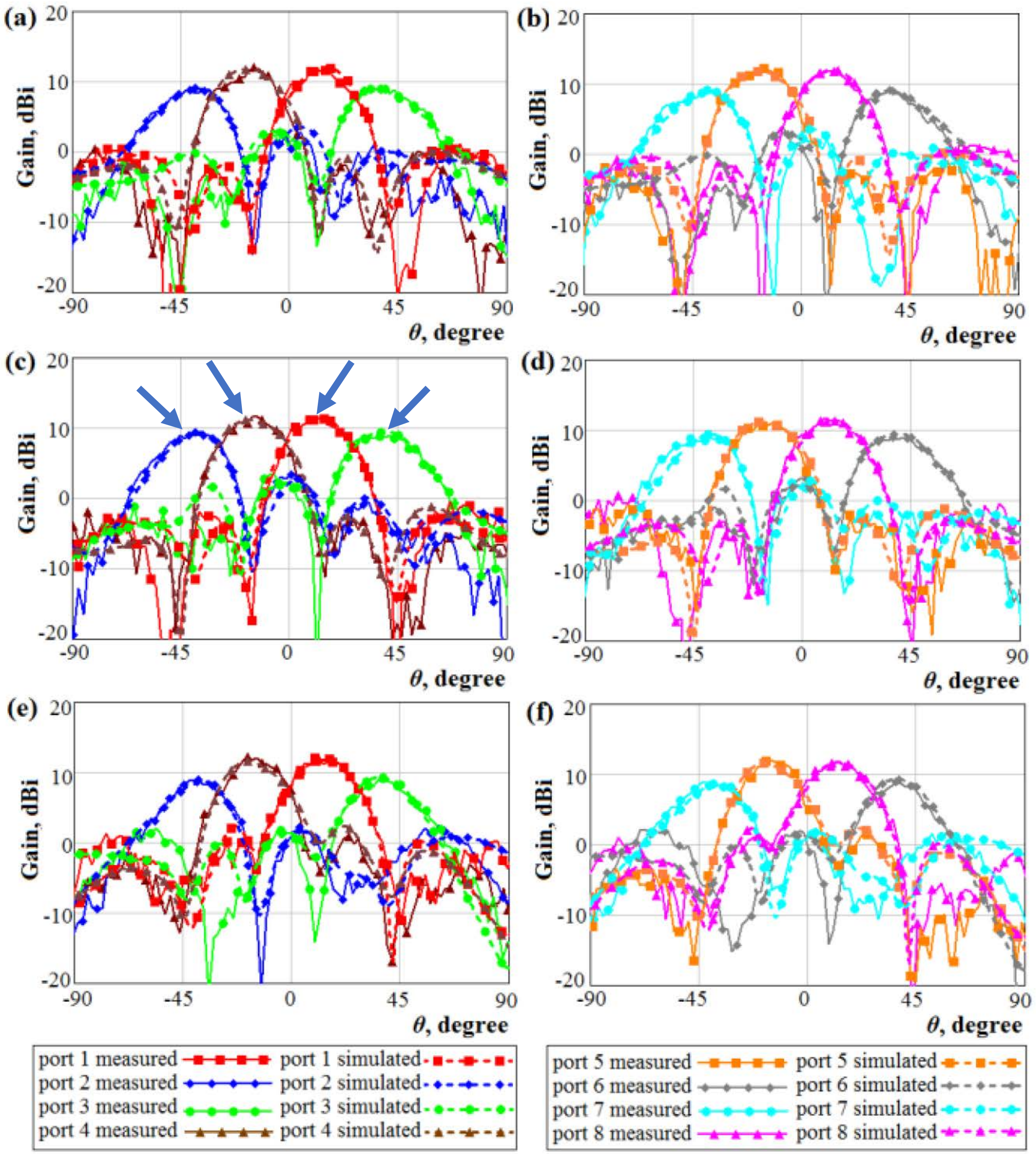

(a)
Y
X
Port 1
Port 2
Port 3
Port 4
Port 5
Port 6
Port 7
Port 8
Power dividers
Butler matrix 1
Butler matrix 2
70 mm
120 mm
(b)
A_1
A_2
A_3
A_4

(a) Complete dual-polarized mm-wave array
(b) The power divider for the two polarizations



(c) Fabricated prototype top

(a) Measured Sxx
(b) Measured Sxy



@ 26 GHz
V-Pol and H-Pol

@ 28.5 GHz
V-Pol and H-Pol

@ 31 GHz
V-Pol and H-Pol

**12 dBi max gain and
9.5dBi min gain**

Potential challenges

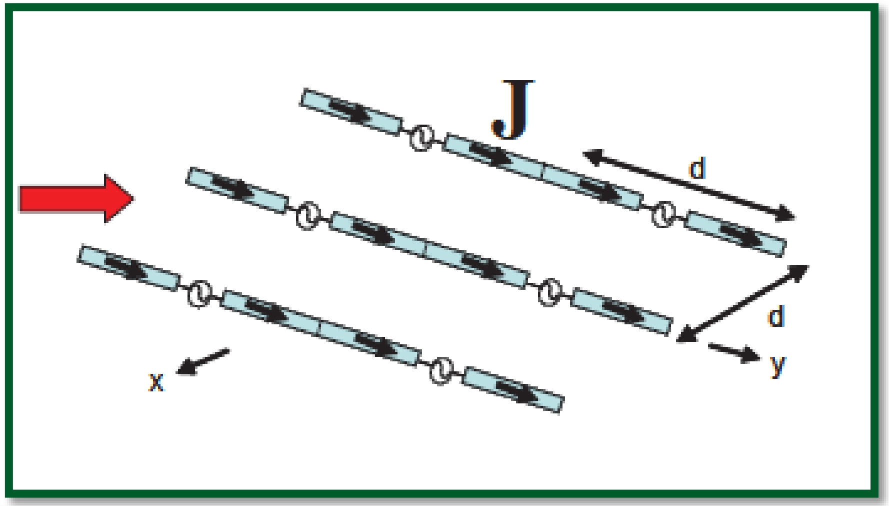
- Mm-wave integration issues within the device, i.e. surroundings, placement, feeding, etc.
- Feeding network design for mm-arrays in an efficient and small form factor way for both Polarizations
- Co-design with active networks, close integration with exciting chipsets
- Beamforming, beam-switching, smart sensing of power levels for automatic beam changes (circuits and algorithms)
- Testing and characterization inside actual devices, i.e. over-the-air (OTA)
- MIMO challenges!!

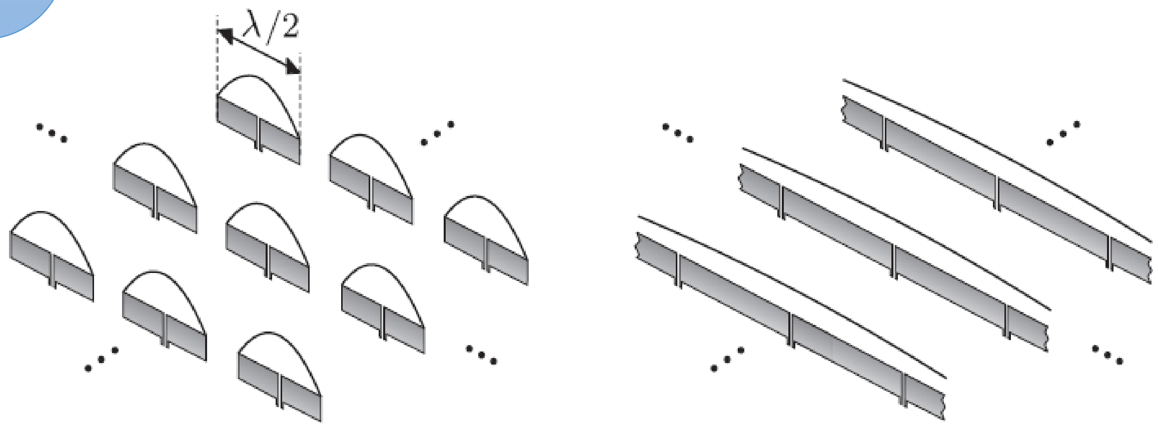
(D) CAA based Integrated Antennas

Connected Antenna Array (CAA)

- ❑ An array of slots or dipoles which are electrically connected to each other [18]
- ❑ Looks like a single antenna but periodically fed

- ❖ Current distributions on connected arrays are almost constant all over the frequency band, i.e. very wide band response





(a) Array of dipoles (b) CAA of Dipoles

[18] D. Cavallo, “Connected Array antennas: Analysis and design," PhD thesis, TNO, The Hague, The Netherlands 2011.

Wide band characteristics:

$$Z_{in} \approx \frac{dy}{dx}\frac{\zeta_o}{2}\frac{\cos\theta}{1-\sin^2\theta\sin^2\theta}$$

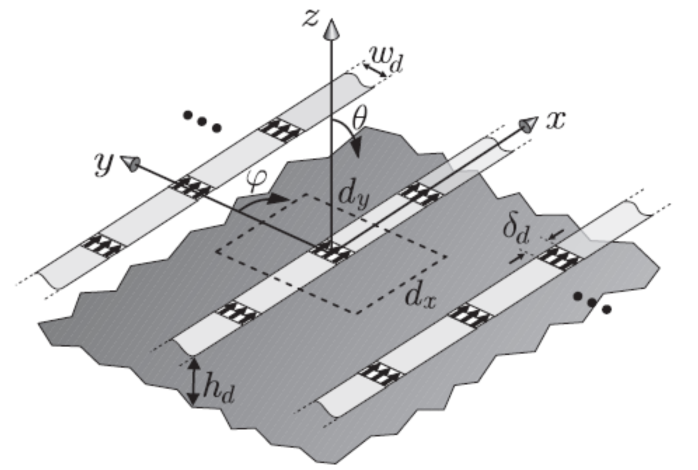
Where, **Z_{in}** is the input impedance of connected slot array, **ζ_o** is impedance of the free space, **θ** is a scan angle, **dy** and **dx** are the single element dimensions in x and y directions, respectively.

Where,
Eɵ=theta component of E-filed
Eφ=phi component of E-filed
Ax= magnetic vector potential
AF= array factor
N =number of elements
Vo=Excitation volage
Jx=current density
k=2π/λ

Far Field Radiation Patterns:

$$E_\theta \simeq -j\omega cos\theta cos\varphi A_x$$

$$E_\varphi \simeq j\omega sin\varphi A_x$$



Connected antenna array of dipoles [18].

$$A_x(\mathbf{r}) \approx J_x(k_0 sin\theta cos\varphi, k_0 sin\theta sin\varphi)\frac{\mu e^{-jk_0 r}}{4\pi r}(1-e^{-jk_0 2h_d cos\theta}) \quad (2)$$

$$J_x(k_x,k_y) \approx -V_0 AF(k_y-k_{y0},N_y,d_y)AF(k_x-k_{x0},N_x,d_x)J_0\left(\frac{k_y w_d}{2}\right)\frac{sinc\left(\frac{k_x\delta_d}{2}\right)}{D_\infty(k_{xm})} \quad (3)$$

$$AF(k-k_d,N,d)=\sum_{n=-N/2}^{N/2} e^{j(k-k_d)nd} \quad (4)$$

Example 1

- **The First Dual-Function** Connected Antenna Array (CAA)
- CAA at 12.5GHz, and acts as a DGS at 2GHz
- BW achieved:

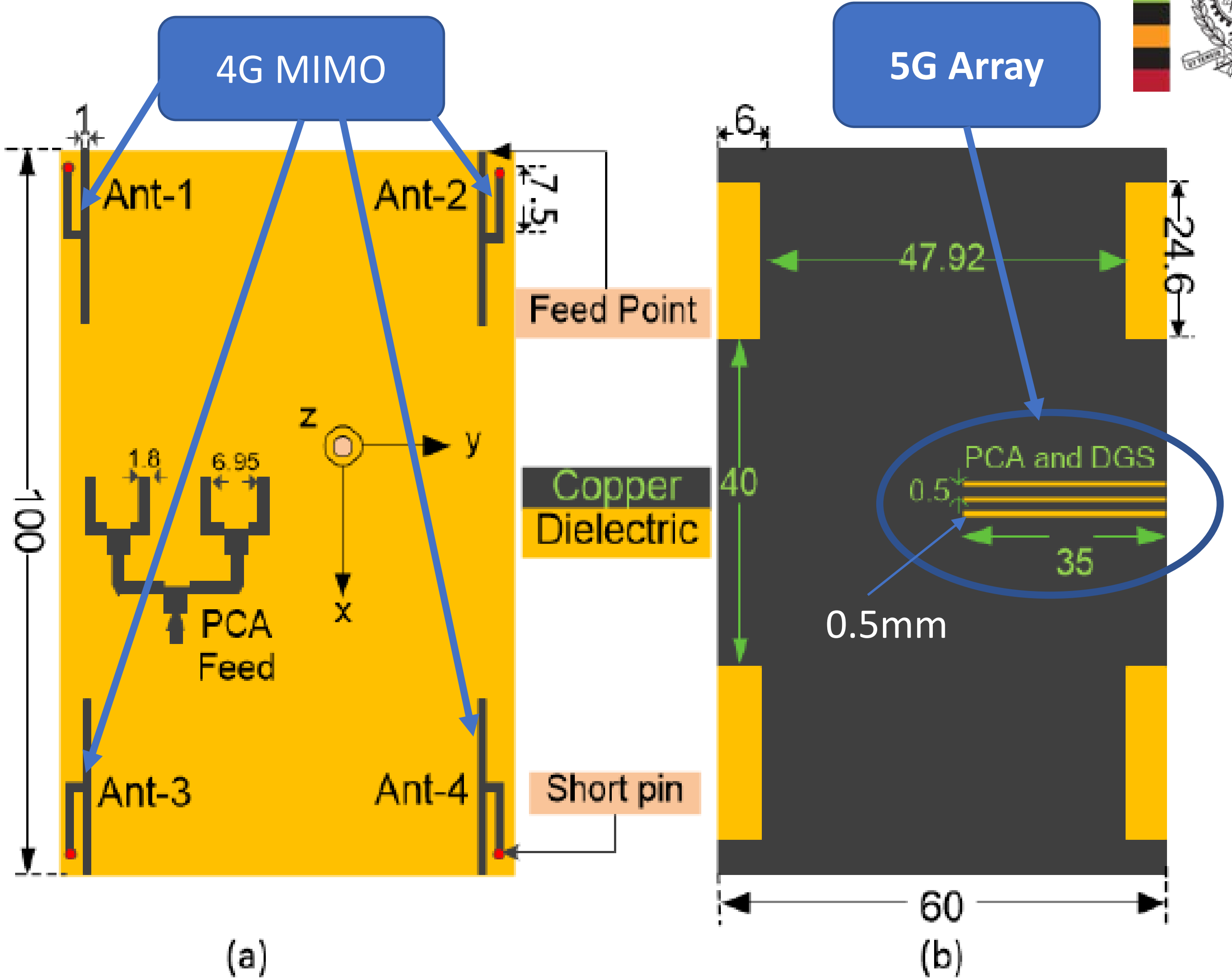
2.058-2.263 GHz

(205 MHz)

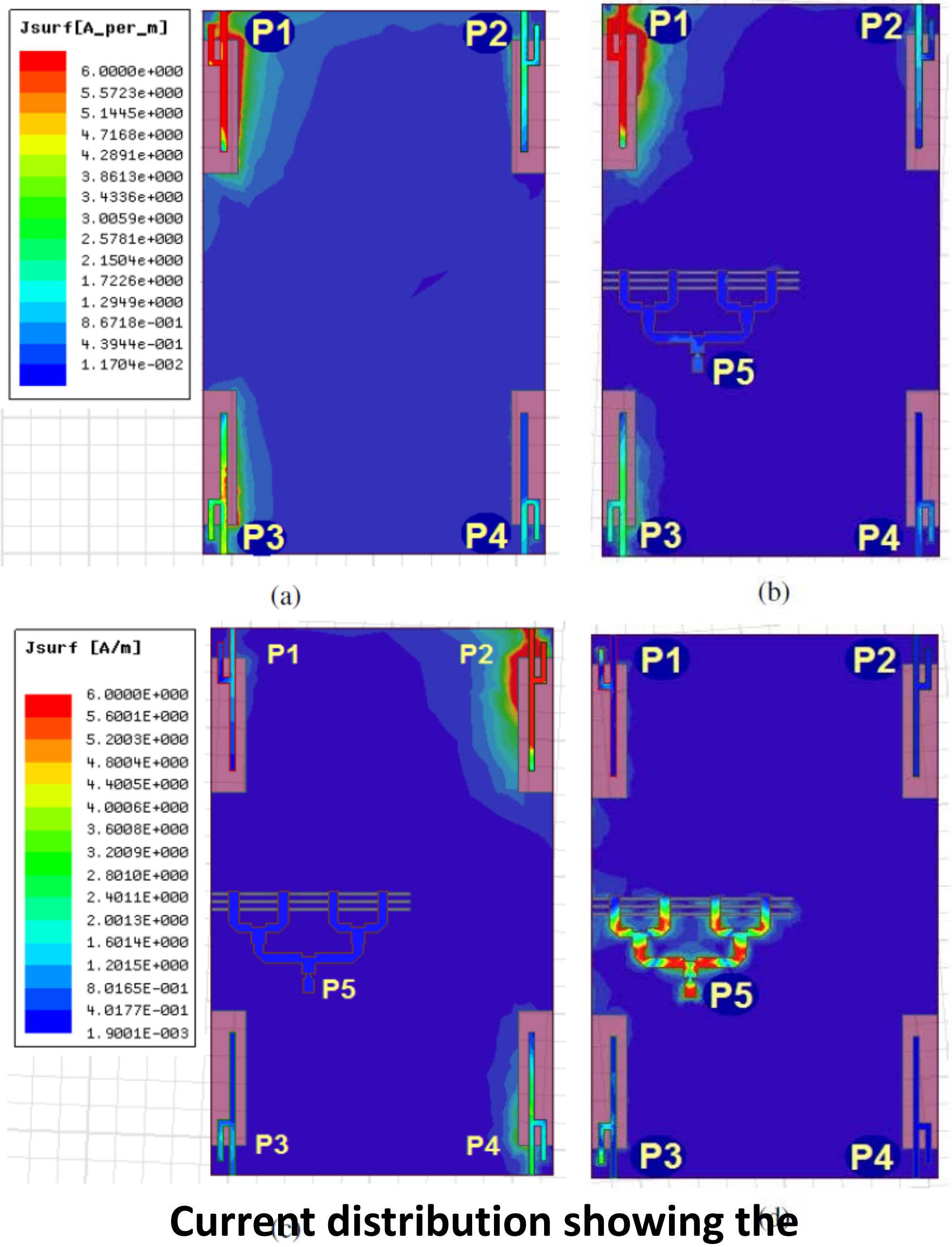
12.17 – 12.75 GHz (580MHz

- Isolation better than 13.5dB

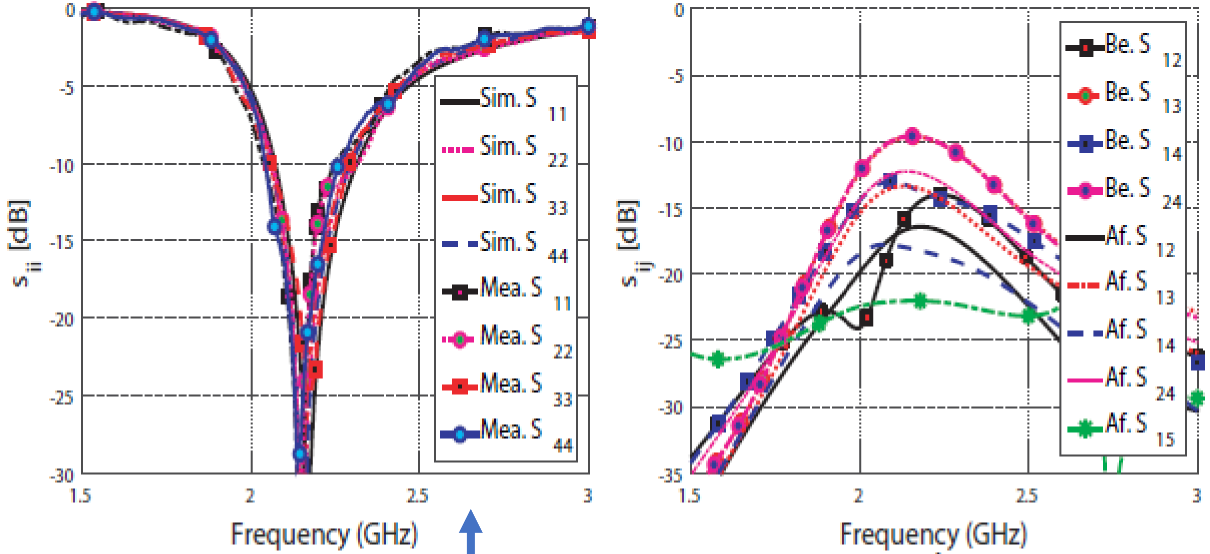
(enhanced by more than 3dB with PCA)


4G MIMO
5G Array
1
Ant-1
Ant-2
7.5
Feed Point
100
1.8
6.95
z
y
x
PCA Feed
Copper
Dielectric
Ant-3
Ant-4
Short pin
(a)
6
47.92
24.6
40
PCA and DGS
0.5
35
0.5mm
60
(b)

[19] M. Ikram, R. Hussain and **M. S. Sharawi**, “A 4G/5G Antenna System with Dual Function Planar Connected Array,” IET Microwaves, Antennas and Propagation, Vol. 11, No. 12, pp. 1760-1764, 2017.

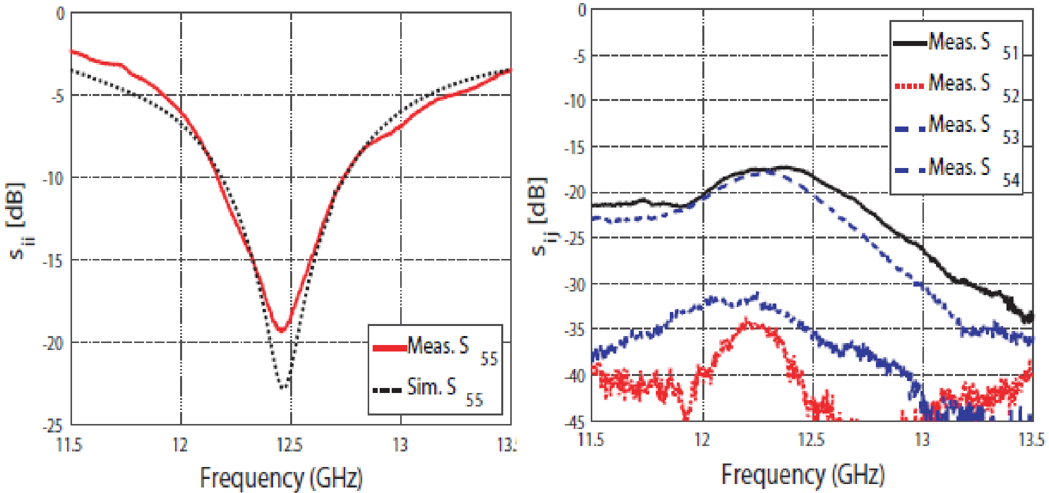

Jsurf[A_per_m]
6.0000e+000
5.5723e+000
5.1445e+000
4.7168e+000
4.2891e+000
3.8613e+000
3.4336e+000
3.0059e+000
2.5781e+000
2.1504e+000
1.7226e+000
1.2949e+000
8.6718e-001
4.3944e-001
1.1704e-002
P1
P2
P3
P4
P5
(a)
(b)
Jsurf [A/m]
6.0000E+000
5.6001E+000
5.2003E+000
4.8004E+000
4.4005E+000
4.0006E+000
3.6008E+000
3.2009E+000
2.8010E+000
2.4011E+000
2.0013E+000
1.6014E+000
1.2015E+000
8.0165E-001
4.0177E-001
1.9001E-003
(c)
(d)

Current distribution showing the DGS behavior

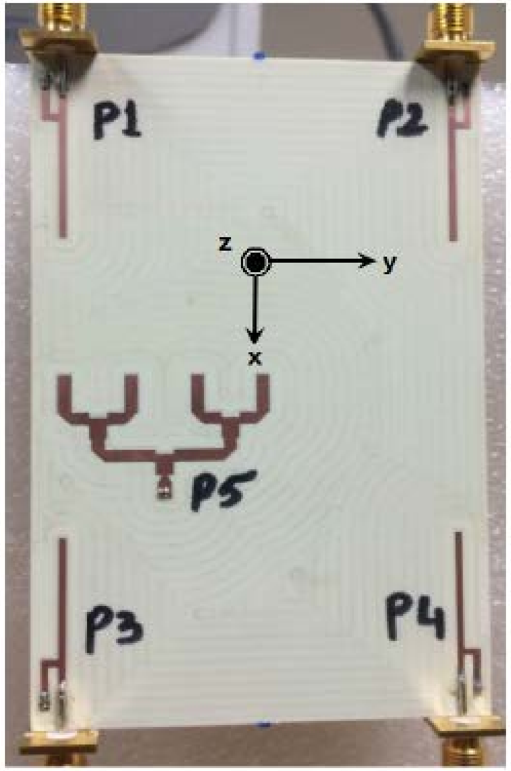


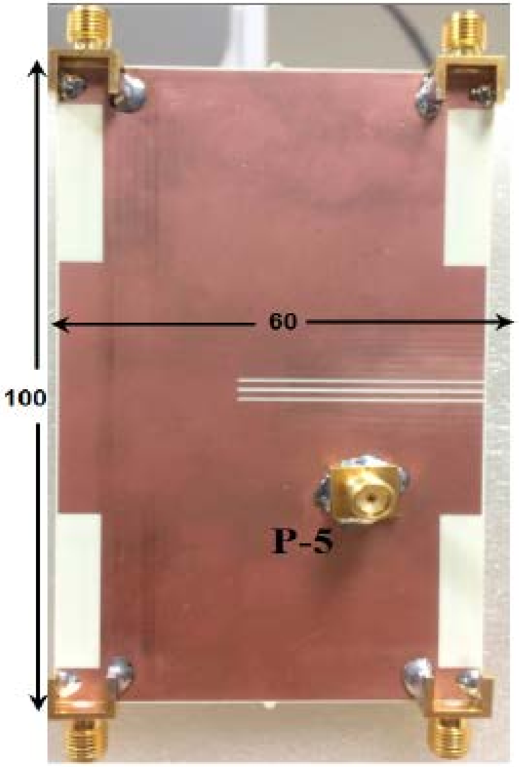
4G @ 2 GHz
200 MHz BW
3.5 dBi gain, 74% eff.

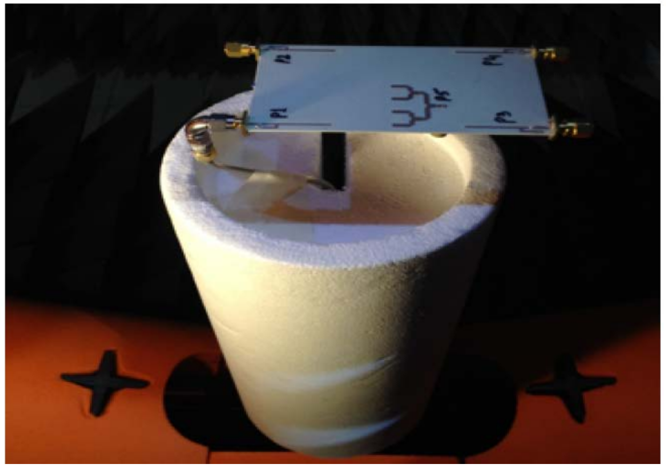
5G @ 12.5 GHz
580 MHz BW
dBi gain, 83% eff.



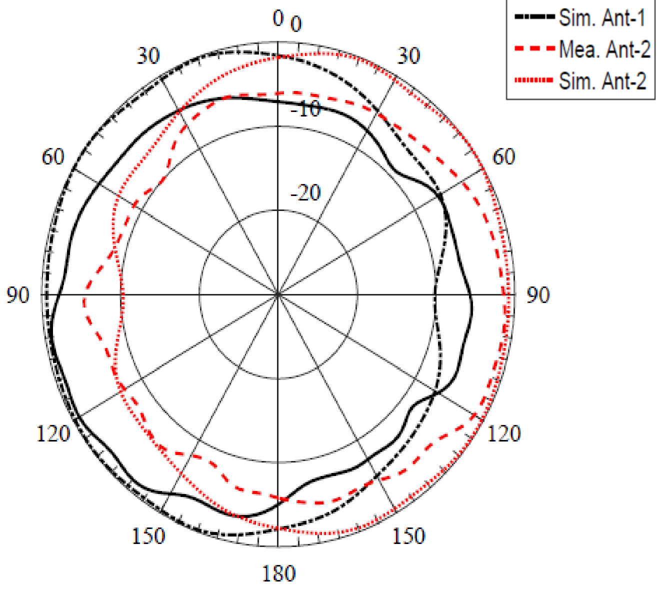
Fabricated Prototype


P1
P2
z
y
x
P5
P3
P4

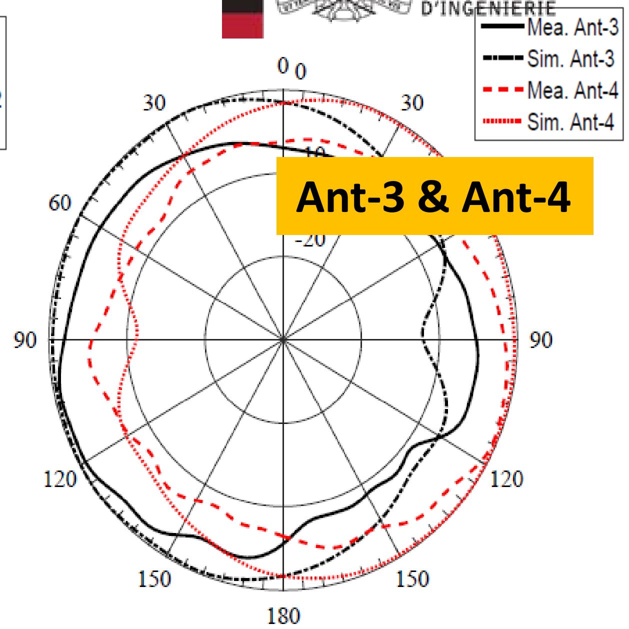




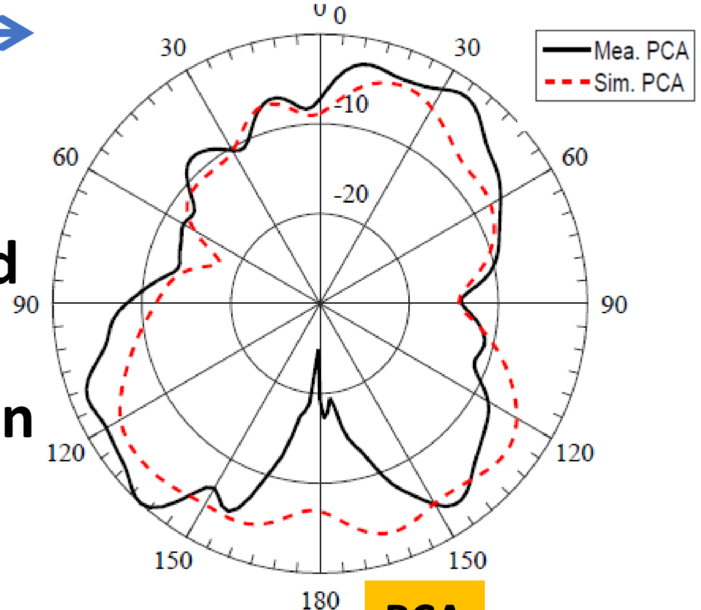
Ant-1 & Ant-2



Ant-3 & Ant-4

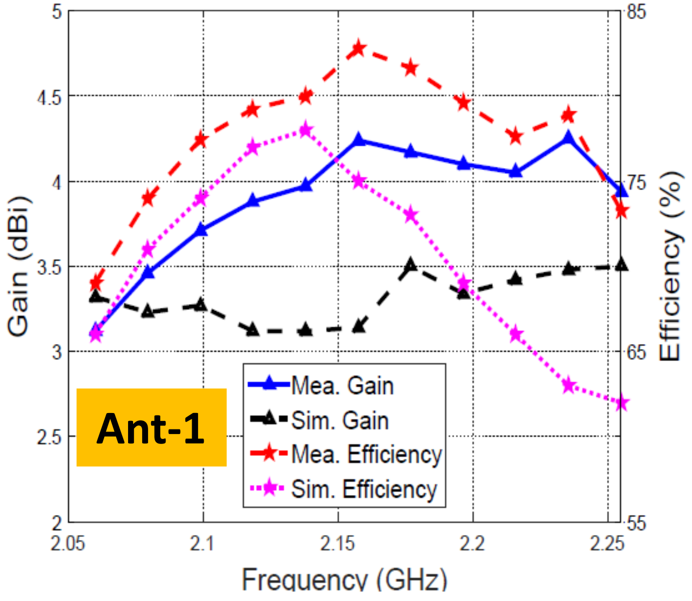


Measured/simulated patterns at center frequencies, elevation cut at ϕ=0º.

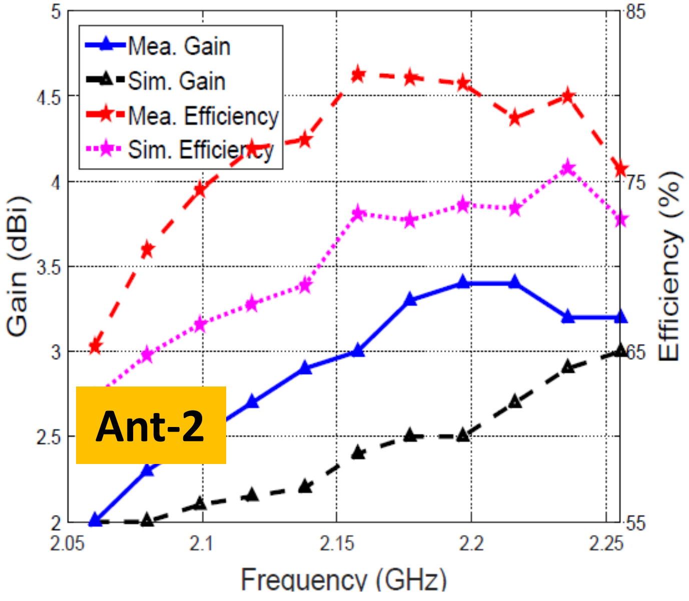


PCA

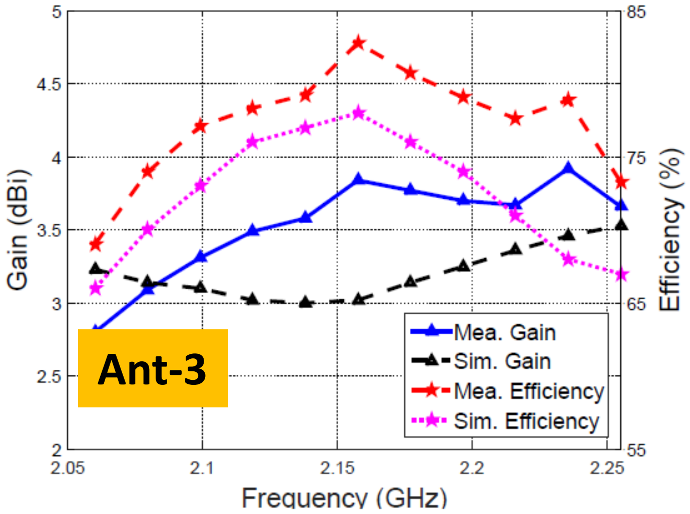
Measured/simulated max gain and efficiencies vs. frequency.\



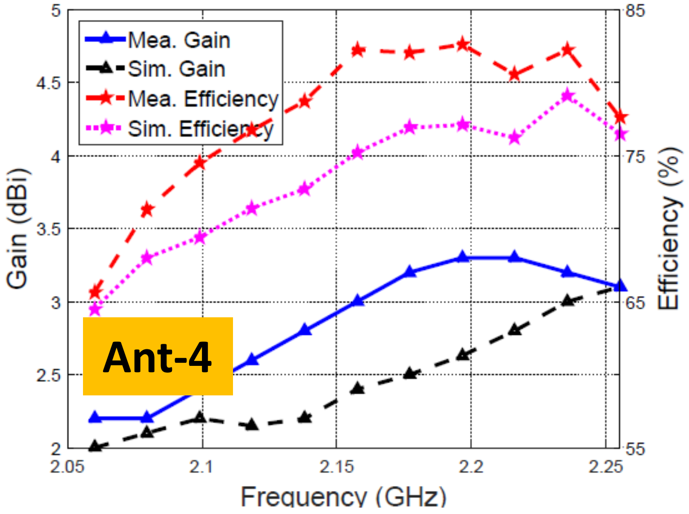
(a)



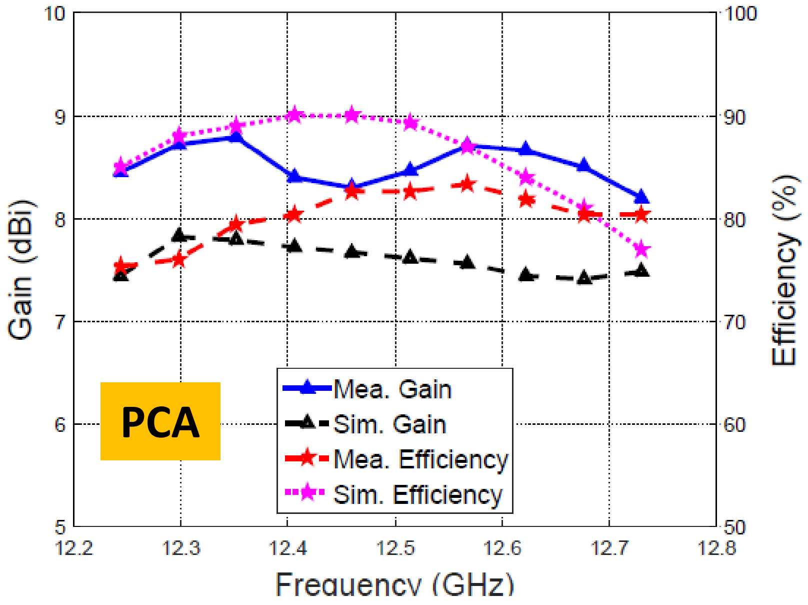
(b)



(c)

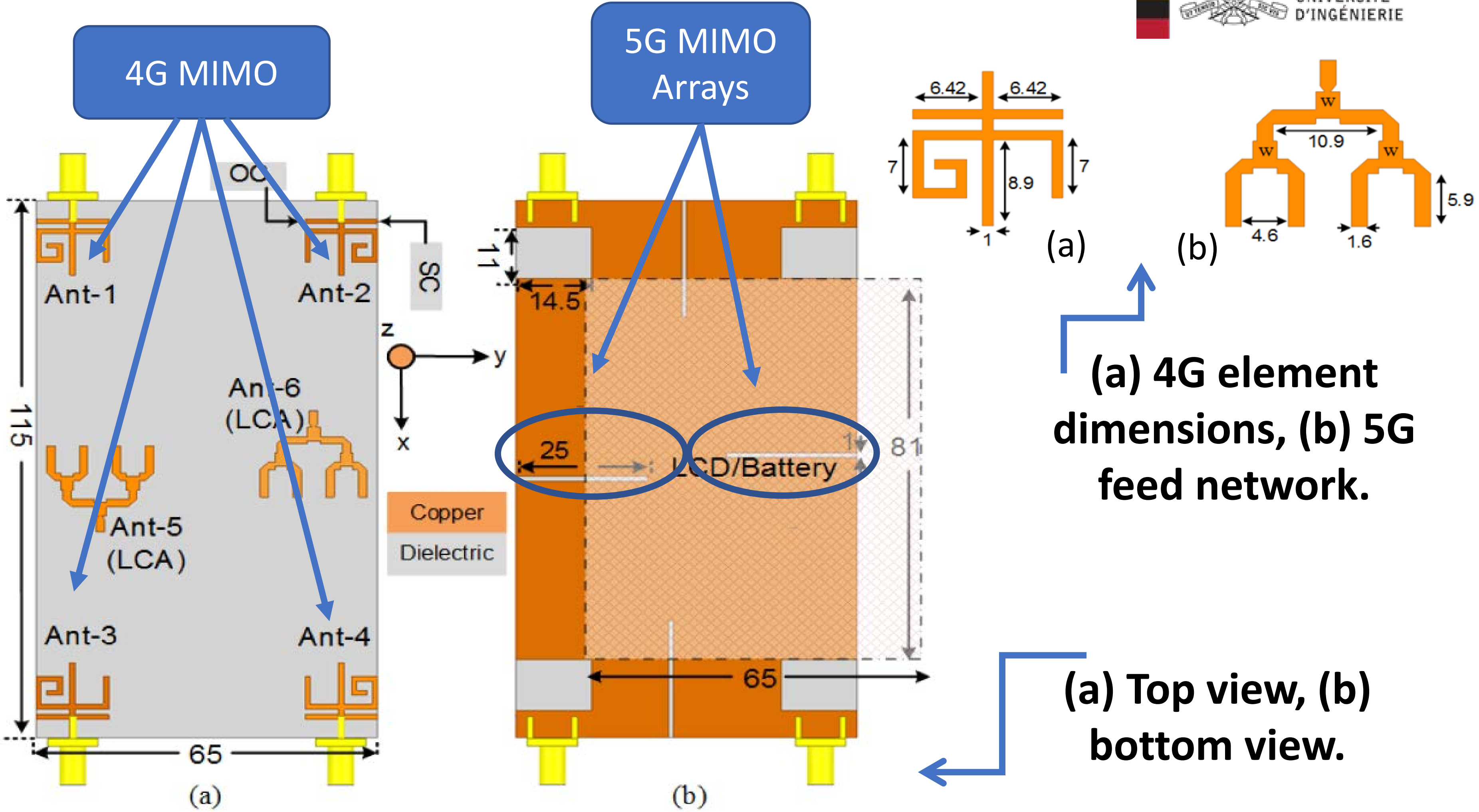


(d)



Example 2:

- CAA based with dual functions
- 1.9-3.2 GHz (4G)
- 4-element 4G MIMO
- 25.7-30.5 GHz operation (5G)
- 2-element 5G MIMO arrays
- Isolation improvement of 3dB due to 5G slots


Ant-1
Ant-2
OC
SC
z
y
x
Ant-6
(LCA)
Ant-5
(LCA)
Ant-3
Ant-4
115
65
(a)
11
14.5
25
LCD/Battery
81
65
(b)
Copper
Dielectric
6.42
6.42
7
8.9
7
1
(a)
W
10.9
W
W
5.9
4.6
1.6
(b)

4G MIMO

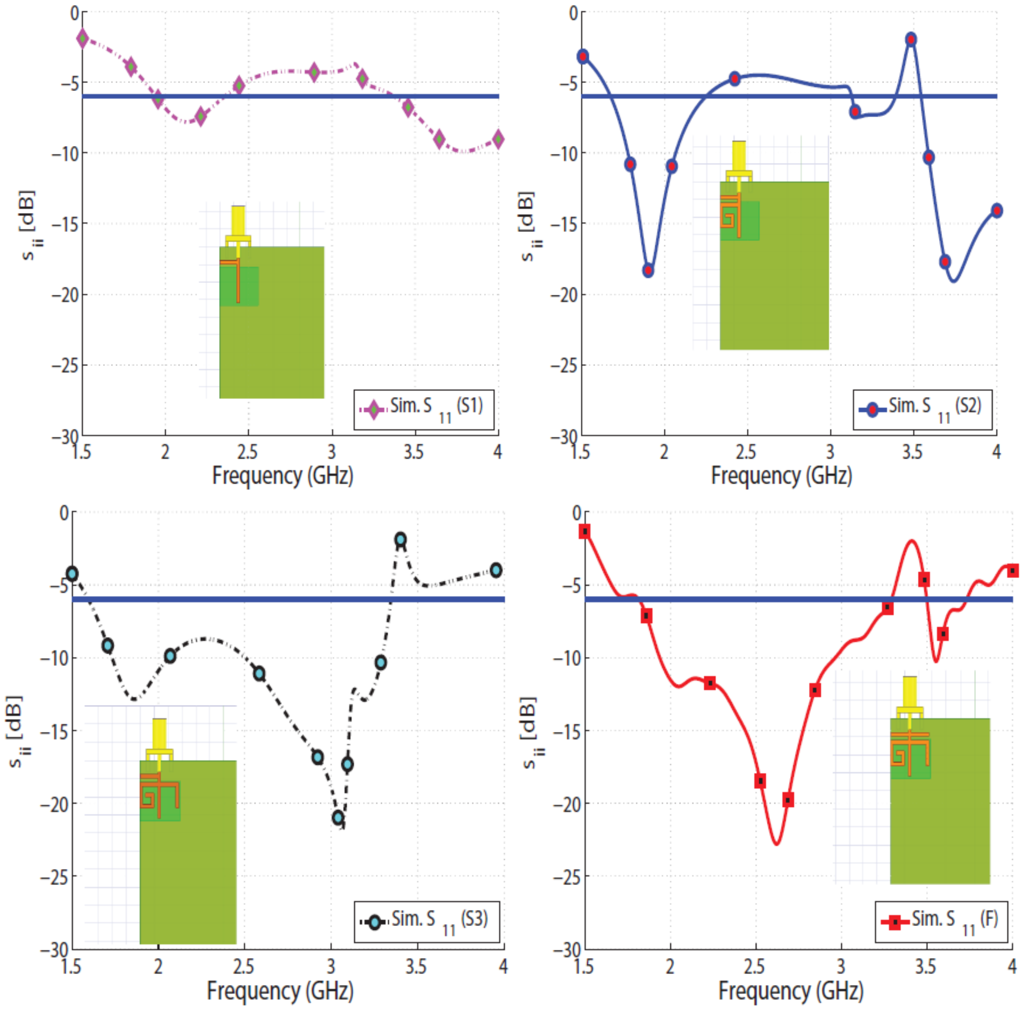
5G MIMO Arrays

(a) 4G element dimensions, (b) 5G feed network.

(a) Top view, (b) bottom view.

[20] M. Ikram, **M. S. Sharawi**, A. Shamim and A. Sebak, “A Multi-Band Dual-Standard MIMO Antenna System Based on Monopoles (4G) and Connected Slots (5G),” Microwaves and Optical Technology Letters, Wiley, Vol. 60, No. 6, 1468-1476, June 2018.

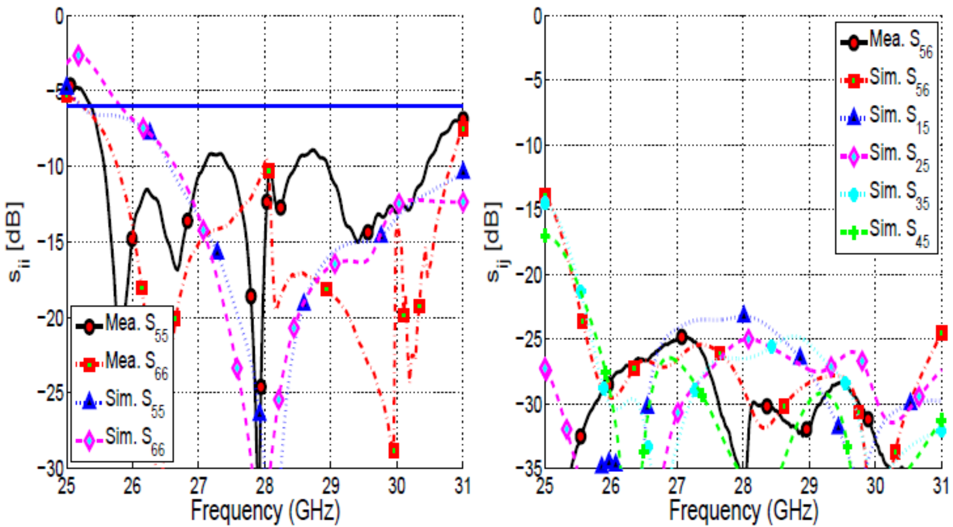
POLYTECHNIQUE MONTRÉAL
UNIVERSITÉ D'INGÉNIERIE



(c)

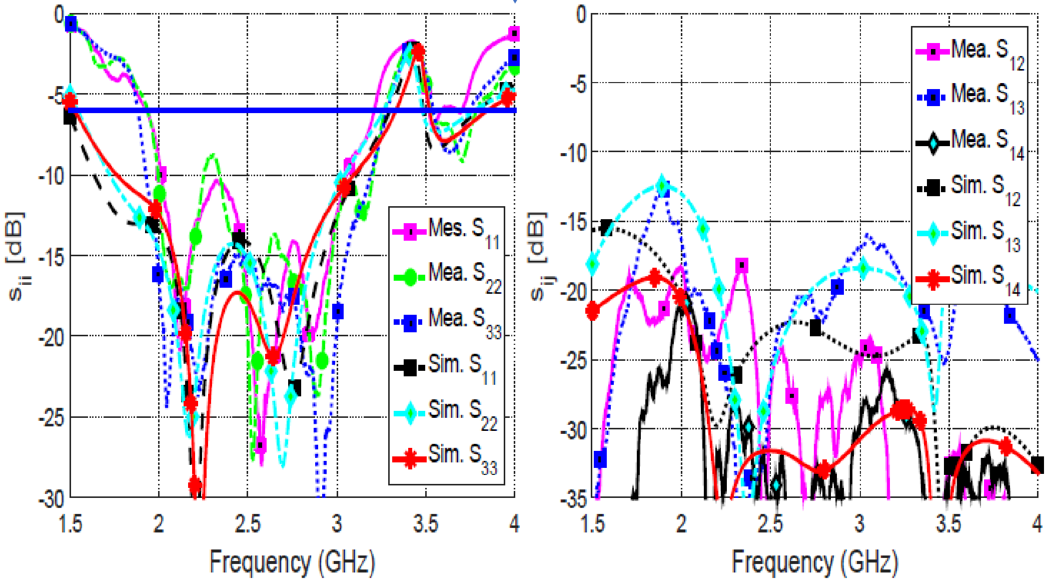
(d)

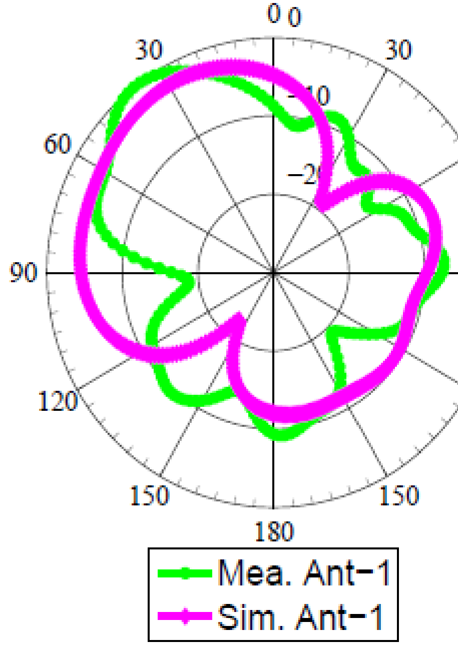
Evolution steps of the 4G antenna.
1.9 – 3.2GHz (1.3GHz BW)
3.5 – 3.7 GHz (200MHz BW)

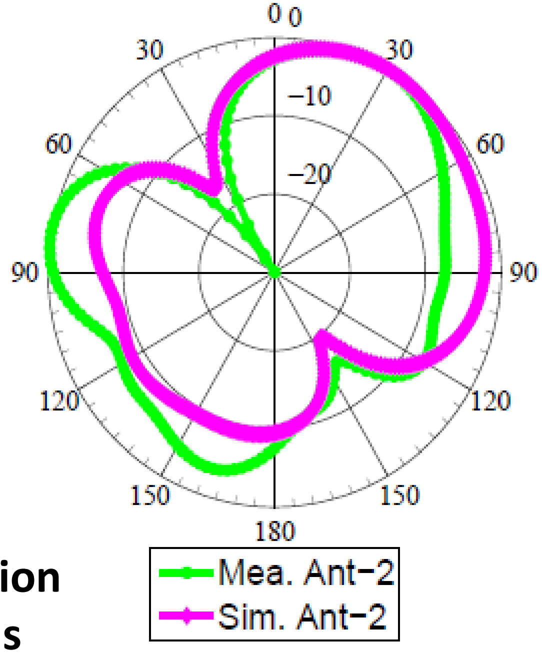


5G , 25.4 - 31 GHz
4.8 GHz BW

4G , 1.9 – 3.2 / 3.5-3.7 GHz
1300 / 200 MHz BW

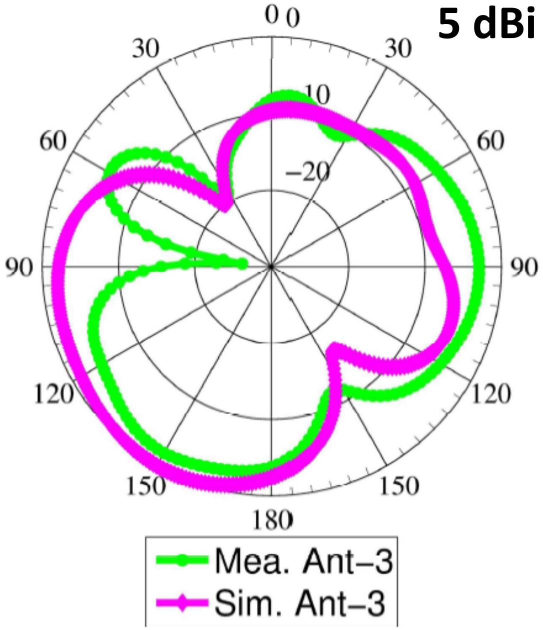


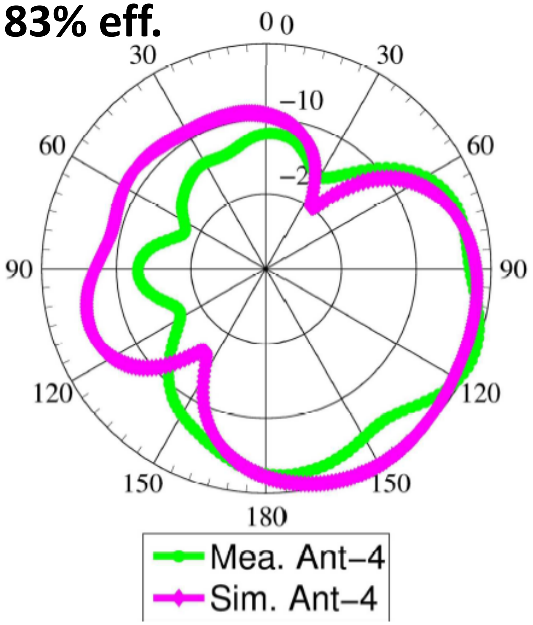


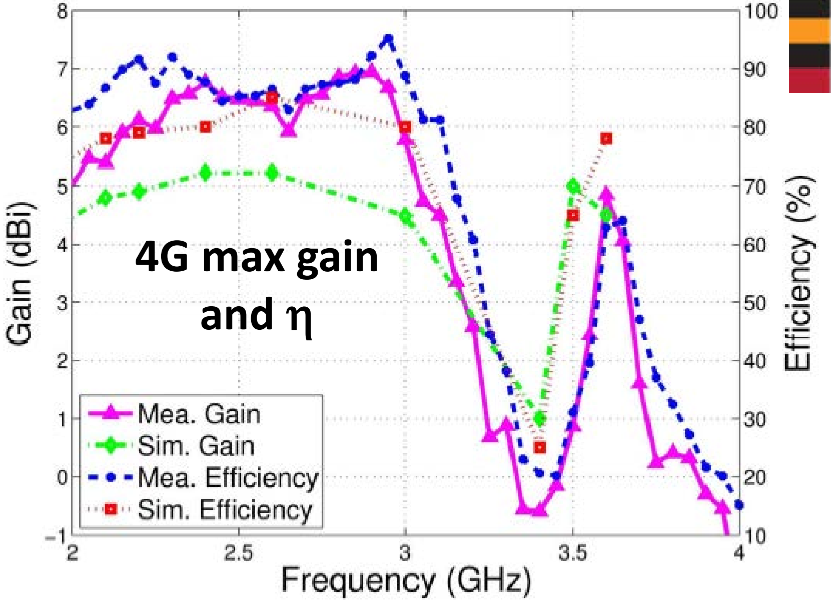


4G radiation patterns

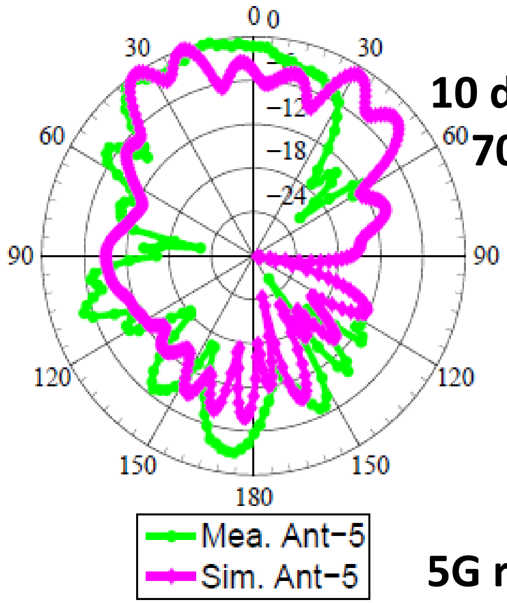
5 dBi gain, 83% eff.



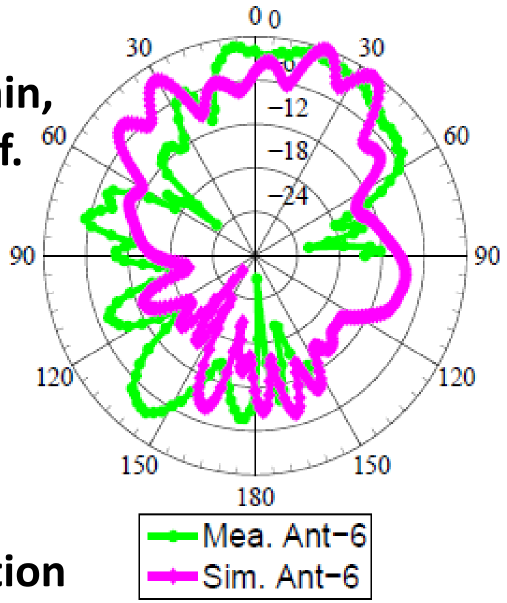




4G max gain and η



10 dBi gain, 70% eff.



5G radiation patterns

(E) Massive MIMO Antenna Systems:

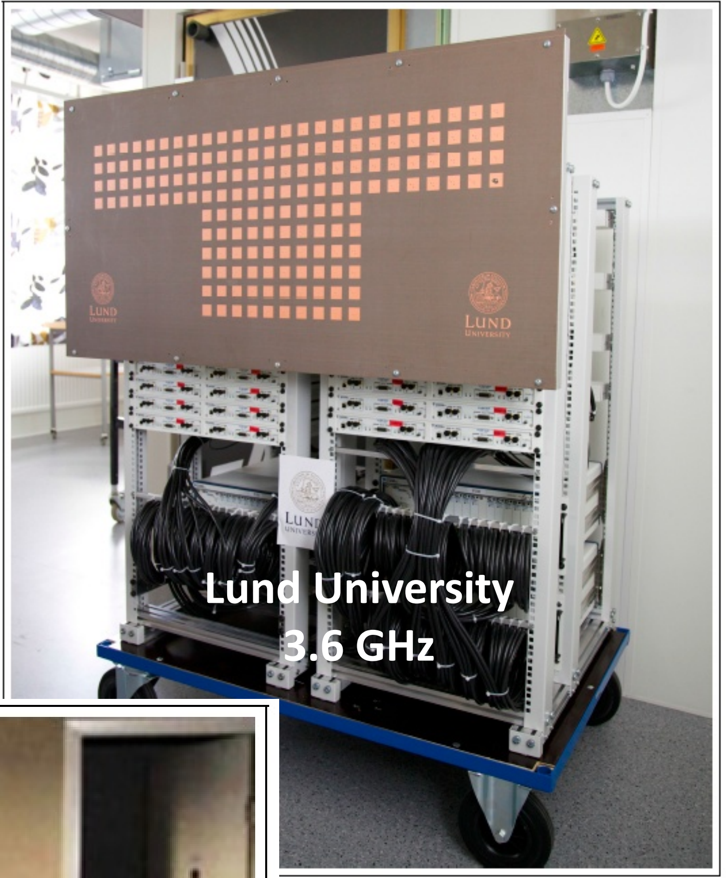
- Massive MIMO (M-MIMO) is a system where 100's of antennas are deployed at the base-station side

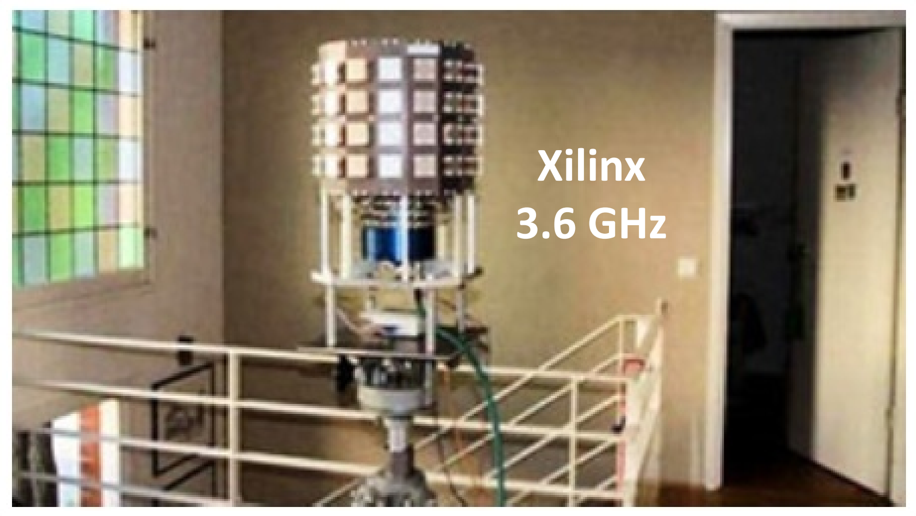
- Operating frequencies vary from 3-30GHz (initial proof of concepts)

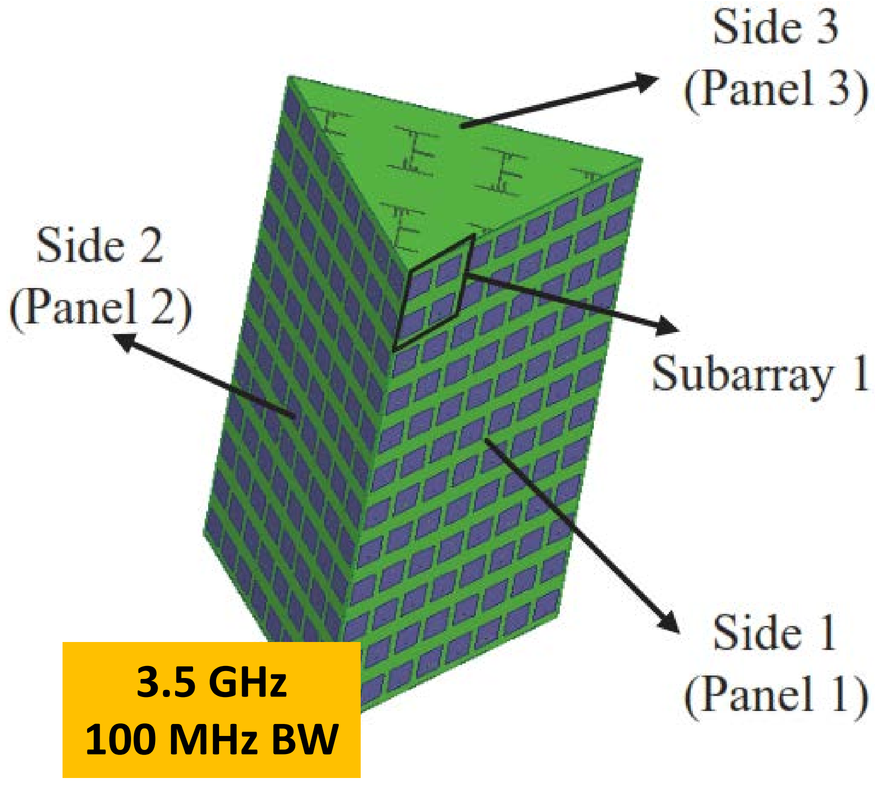
- Several academic and industrial

Features:

- Capacity improvement
- Reduction in latency
- Energy efficiency
- Inexpensive low-power parts
- Robustness against Jamming

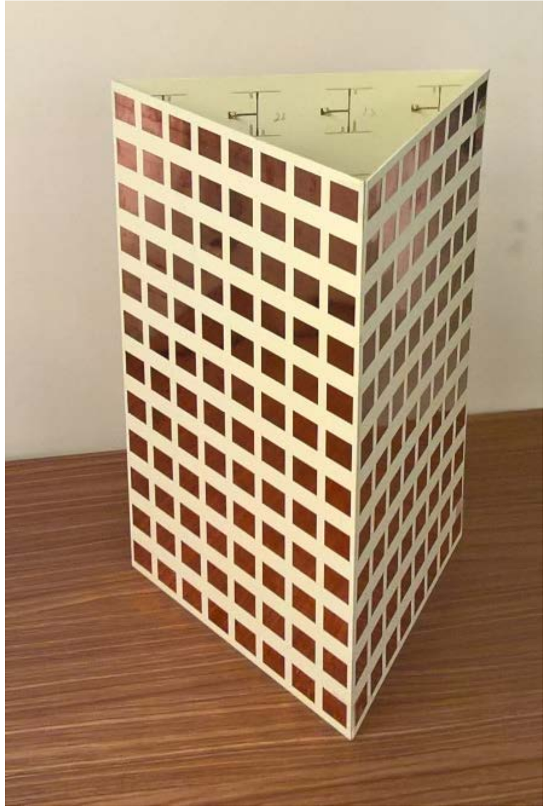

Lund University
3.6 GHz

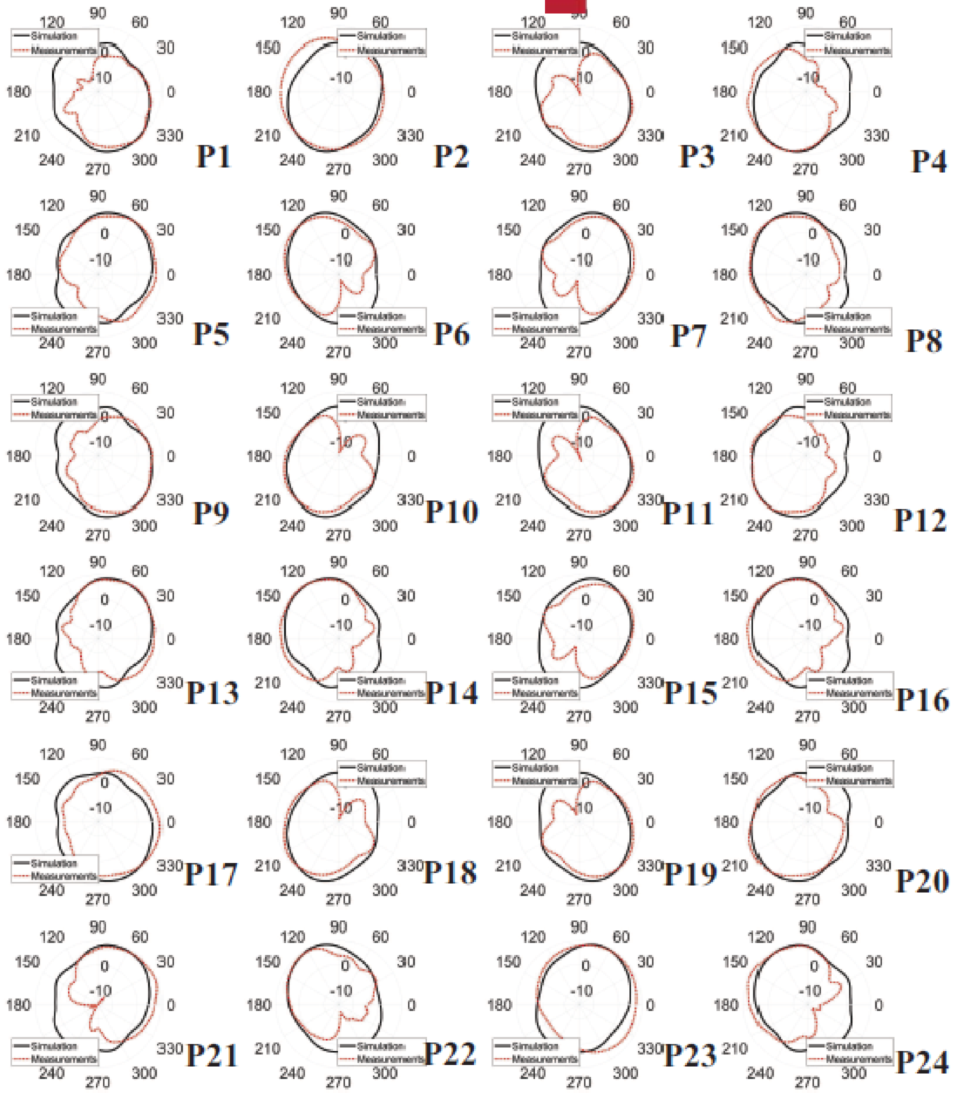

Xilinx
3.6 GHz


Side 3
(Panel 3)
Side 2
(Panel 2)
Subarray 1
Side 1
(Panel 1)

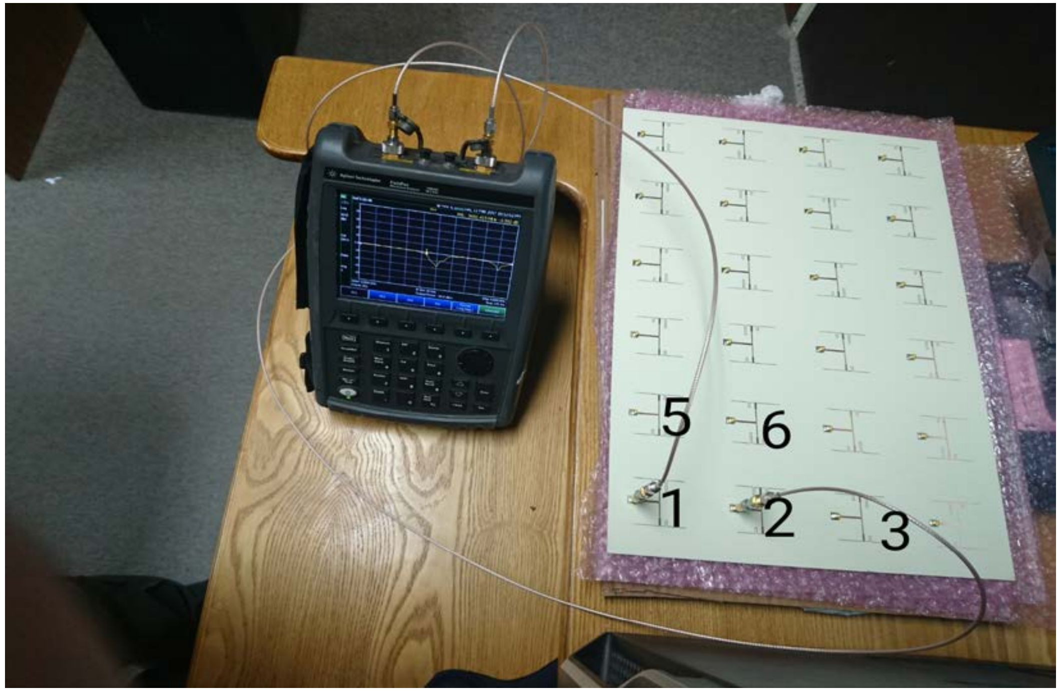
3.5 GHz
100 MHz BW

- **72 ports**
- **288 patch elements**
- **3 sectors (can be made 6)**

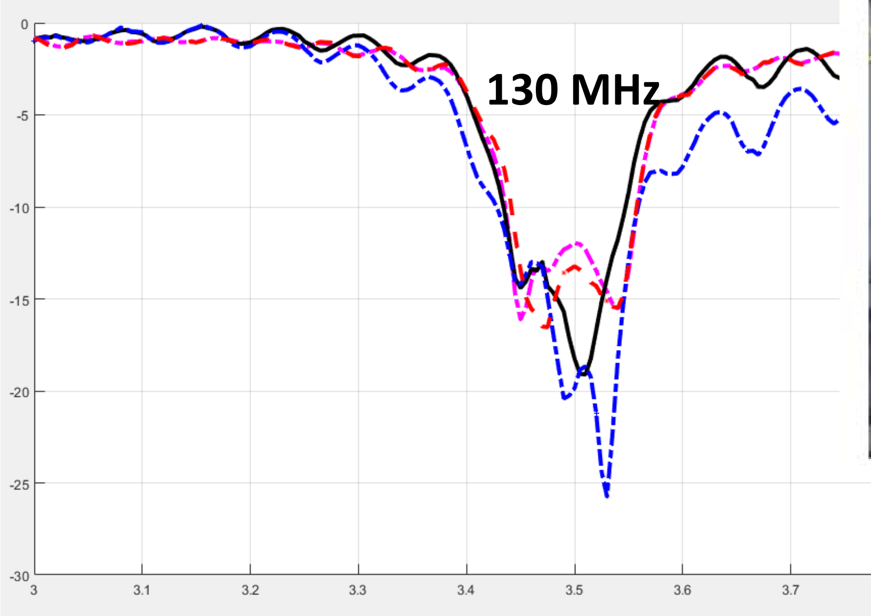


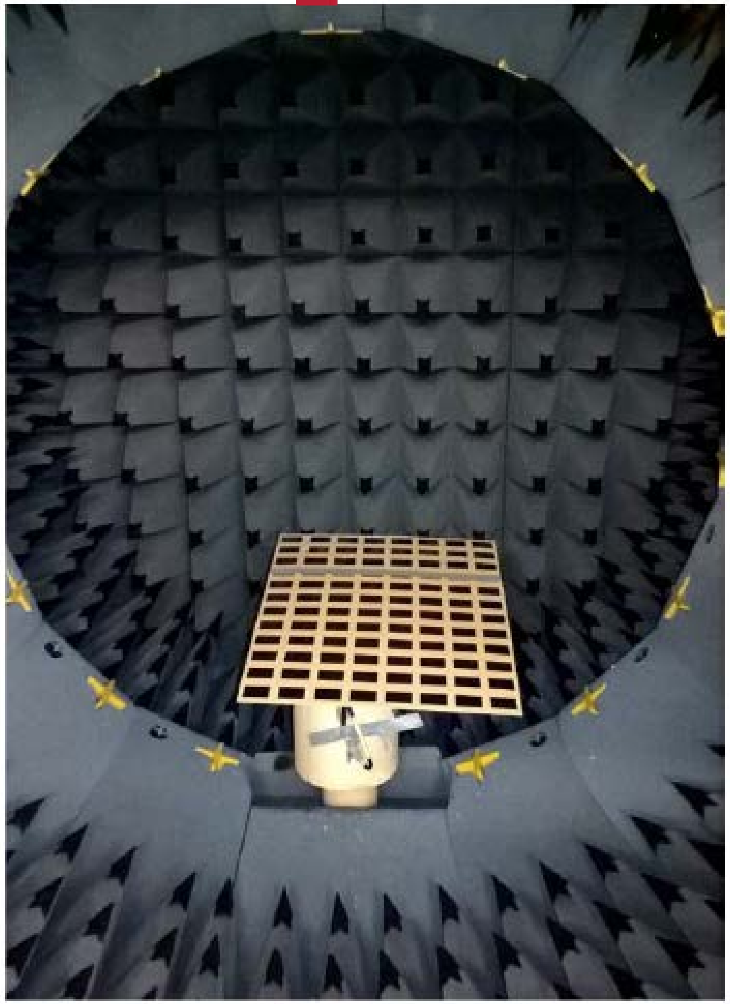


[21] M. Al-Tarifi, **M. S. Sharawi** and A. Shamim, “A Massive MIMO Antenna System for 5G Base Stations with Directive Ports and Switched Beamsteering Capabilities,” IET Microwaves, Antennas and Propagation, Vol. 12, No. 10, pp. 1709-1718, August 2018.

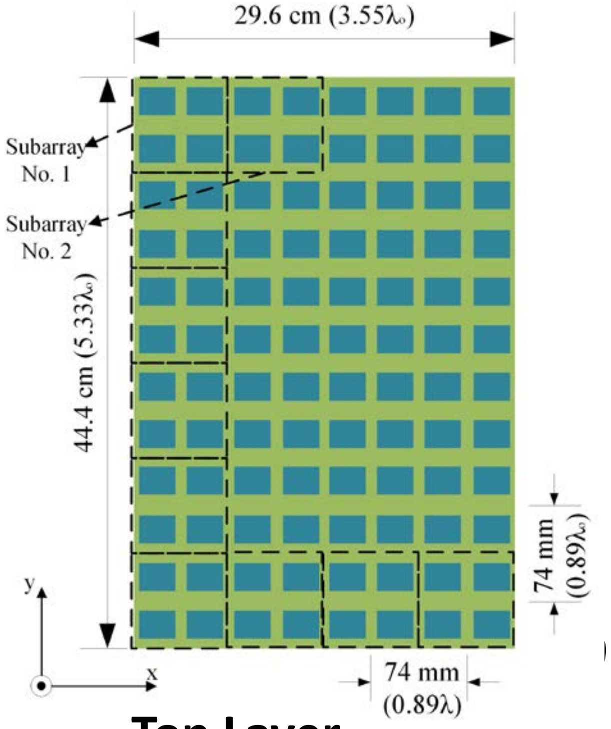


- Fabricated prototype was tested for port parameters at KFUPM.
- Pattern measurements were done in KAUST Satimo Chamber

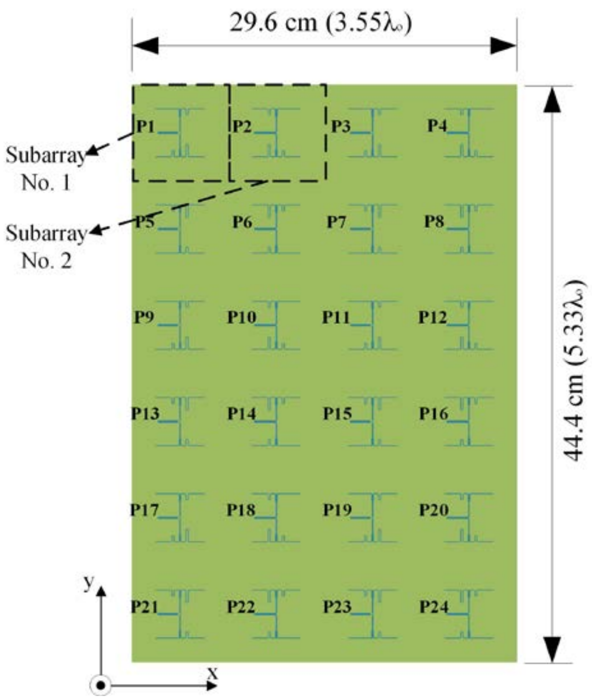




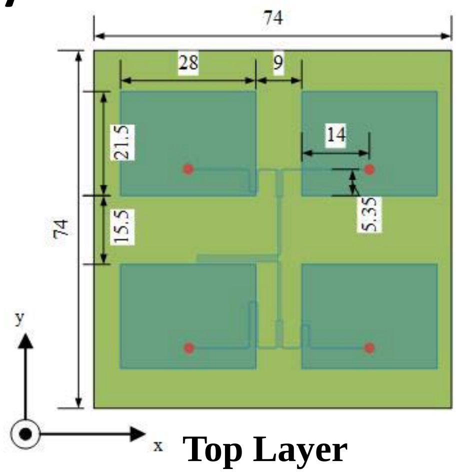
(24 ports panel Design)


29.6 cm (3.55λ₀)
Subarray No. 1
Subarray No. 2
44.4 cm (5.33λ₀)
74 mm (0.89λ₀)
74 mm (0.89λ)
y
x

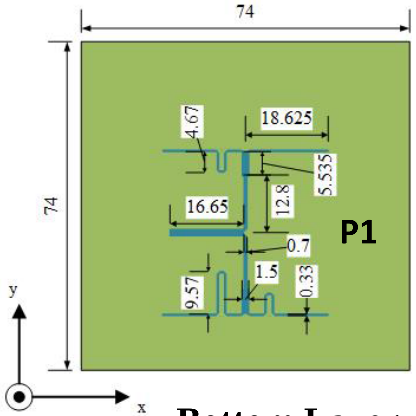
Top Layer


29.6 cm (3.55λ₀)
Subarray No. 1
Subarray No. 2
P1
P2
P3
P4
P5
P6
P7
P8
P9
P10
P11
P12
P13
P14
P15
P16
P17
P18
P19
P20
P21
P22
P23
P24
44.4 cm (5.33λ₀)
y
x

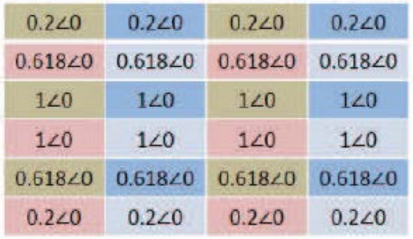
Bottom Layer


74
28
9
14
21.5
15.5
5.35
74
y
x

Top Layer
(in mm)

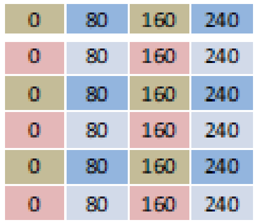

74
4.67
18.625
5.535
16.65
12.8
0.7
1.5
9.57
0.33
74
P1
y
x

Bottom Layer
(in mm)

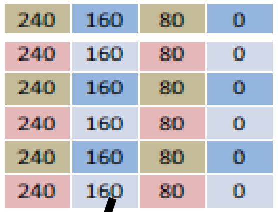


0.2∠0	0.2∠0	0.2∠0	0.2∠0
0.618∠0	0.618∠0	0.618∠0	0.618∠0
1∠0	1∠0	1∠0	1∠0
1∠0	1∠0	1∠0	1∠0
0.618∠0	0.618∠0	0.618∠0	0.618∠0
0.2∠0	0.2∠0	0.2∠0	0.2∠0

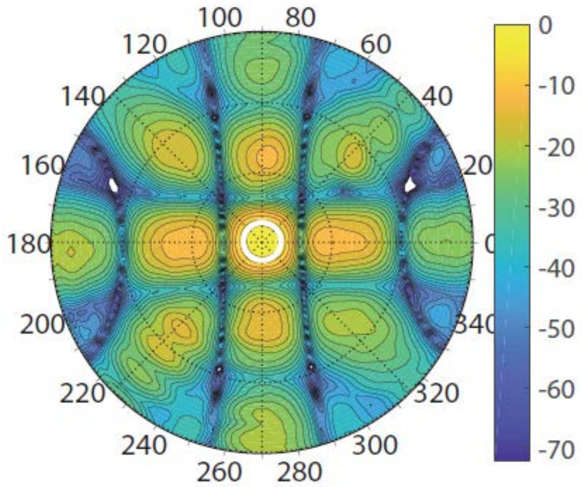
(a)

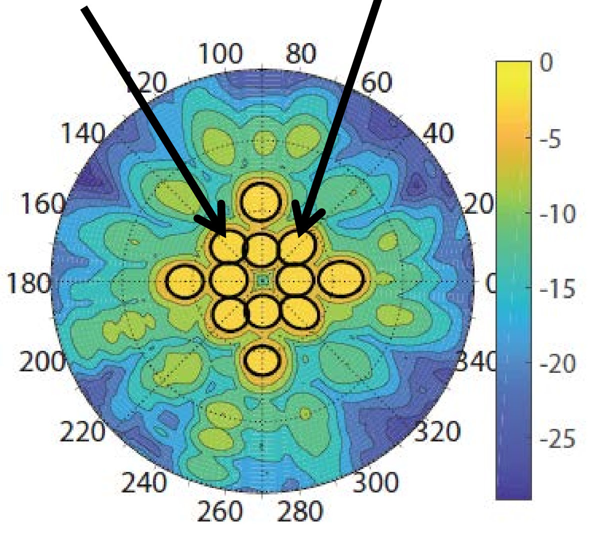


0	80	160	240
0	80	160	240
0	80	160	240
0	80	160	240
0	80	160	240
0	80	160	240



240	160	80	0
240	160	80	0
240	160	80	0
240	160	80	0
240	160	80	0
240	160	80	0



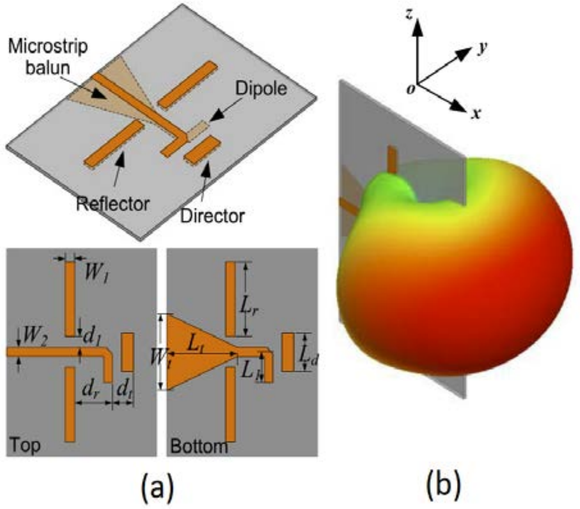


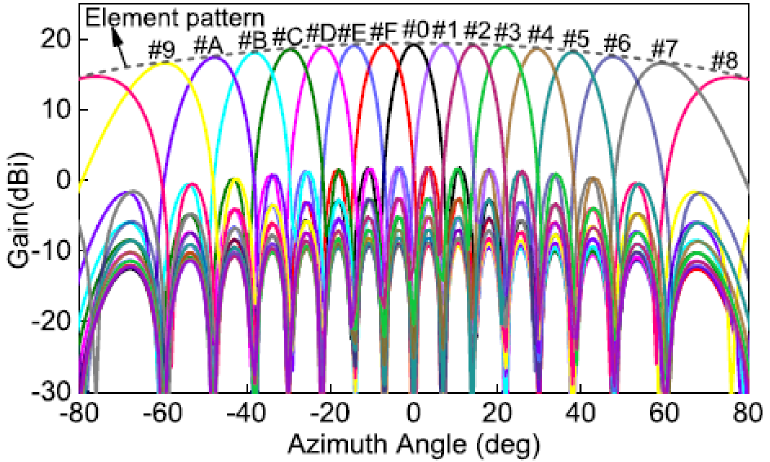
$$E'_{tot} = \sum_{m=1}^{2} \sum_{n=1}^{3}$$

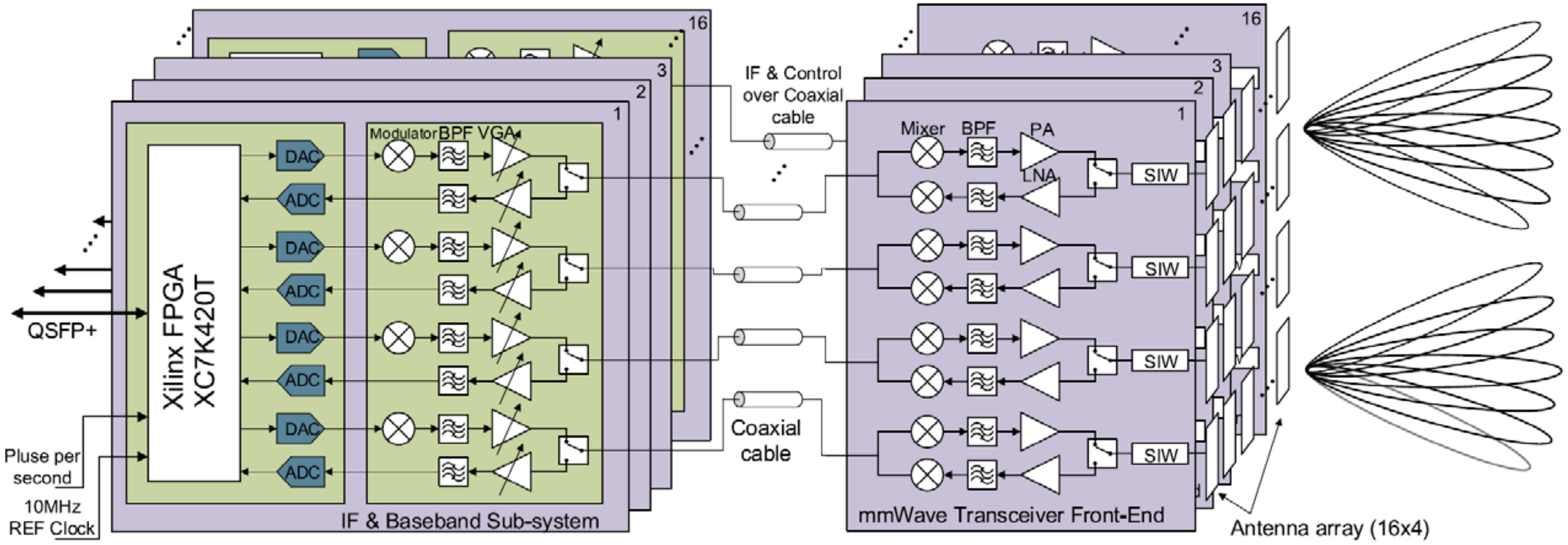
$$I_{(2m-1)(2n-1)} \exp^{j\{(4m-7)\frac{\psi_x}{2}+(4n-9)\frac{\psi_y}{2}+\beta_{(2m-1)(2n-1)}\}} E_1$$
$$+I_{(2m)(2n-1)} \exp^{j\{(4m-5)\frac{\psi_x}{2}+(4n-9)\frac{\psi_y}{2}+\beta_{(2m)(2n-1)}\}} E_2$$
$$+I_{(2m-1)(2n)} \exp^{j\{(4m-7)\frac{\psi_x}{2}+(4n-7)\frac{\psi_y}{2}+\beta_{(2m-1)(2n)}\}} E_3$$
$$+I_{(2m)(2n)} \exp^{j\{(4m-5)\frac{\psi_x}{2}+(4n-7)\frac{\psi_y}{2}+\beta_{(2m)(2n)}\}} E_4)$$

M-MIMO at mm-waves

- 64 channel m-MIMO with full digital Beamforming
- 28GHz band with 500 MHz BW
- 2D antenna array with 16 x 4 elements
- 64 QAM signals with achivable throughput of 5.3 Gpbs for a single fast user, and for 4-channel user terminals can achieve 50.73Gpbs.

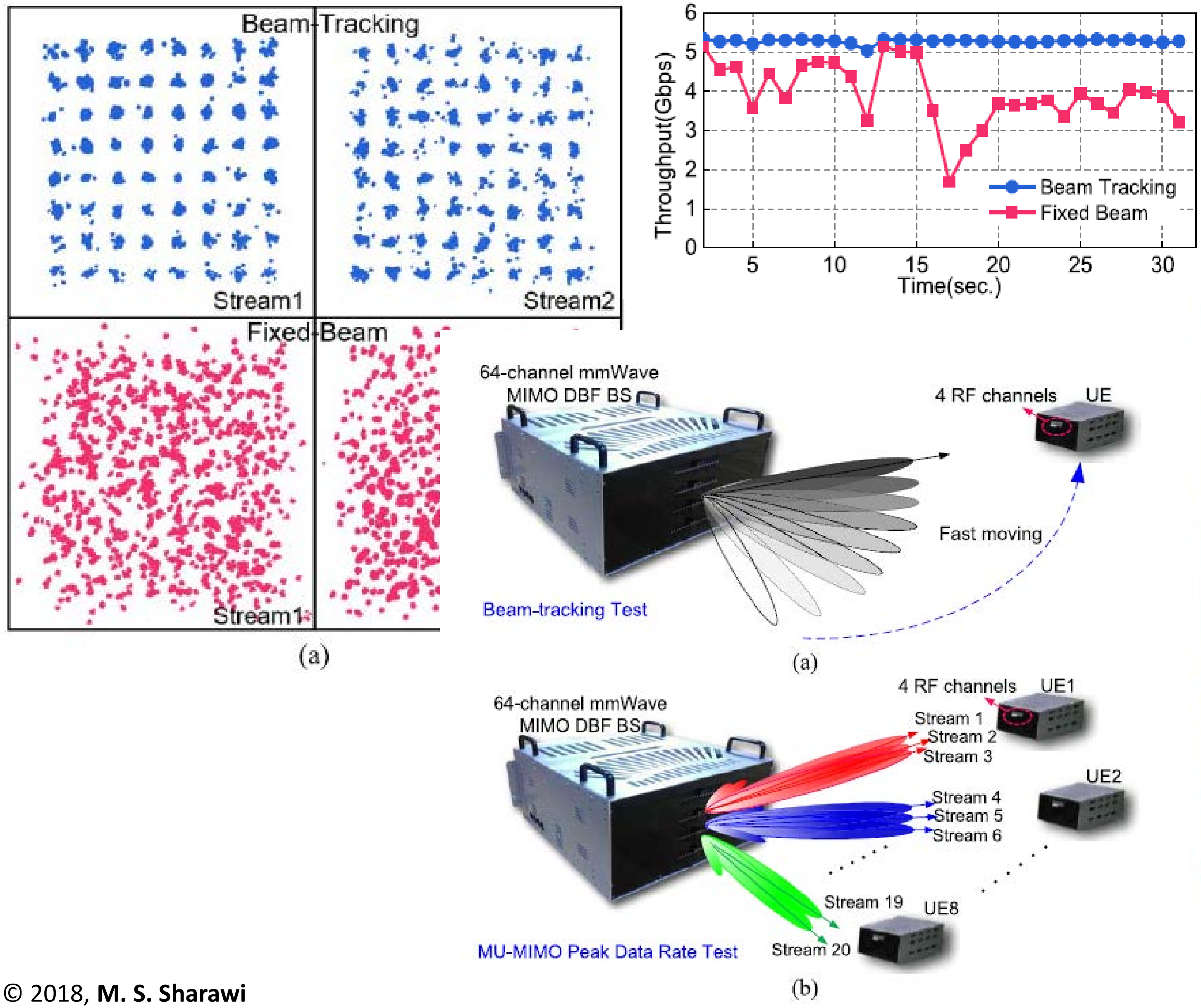

Microstrip balun
Dipole
Reflector
Director
W_1
W_2
d_1
d_r
d_l
Top
L_r
W_l
L_l
L_b
L_d
Bottom
(a)
z
y
o
x
(b)




16
3
2
1
QSFP+
Pluse per second
10MHz REF Clock
Xilinx FPGA XC7K420T
DAC
ADC
Modulator
BPF
VGA
IF & Baseband Sub-system
IF & Control over Coaxial cable
Coaxial cable
Mixer
BPF
PA
LNA
SIW
mmWave Transceiver Front-End
Antenna array (16x4)

[22] B. Yang, Z. Yu, J. Lan, R. Zhang, J. Zhou and W. Hong, "Digital Beamforming Based Massive MIMO Transceiver for 5G Millimeter-Wave Communications," IEEE Transactions on Antennas and Propagation, Vol. 66, No. 7, pp. 3403- 3418, 2018.

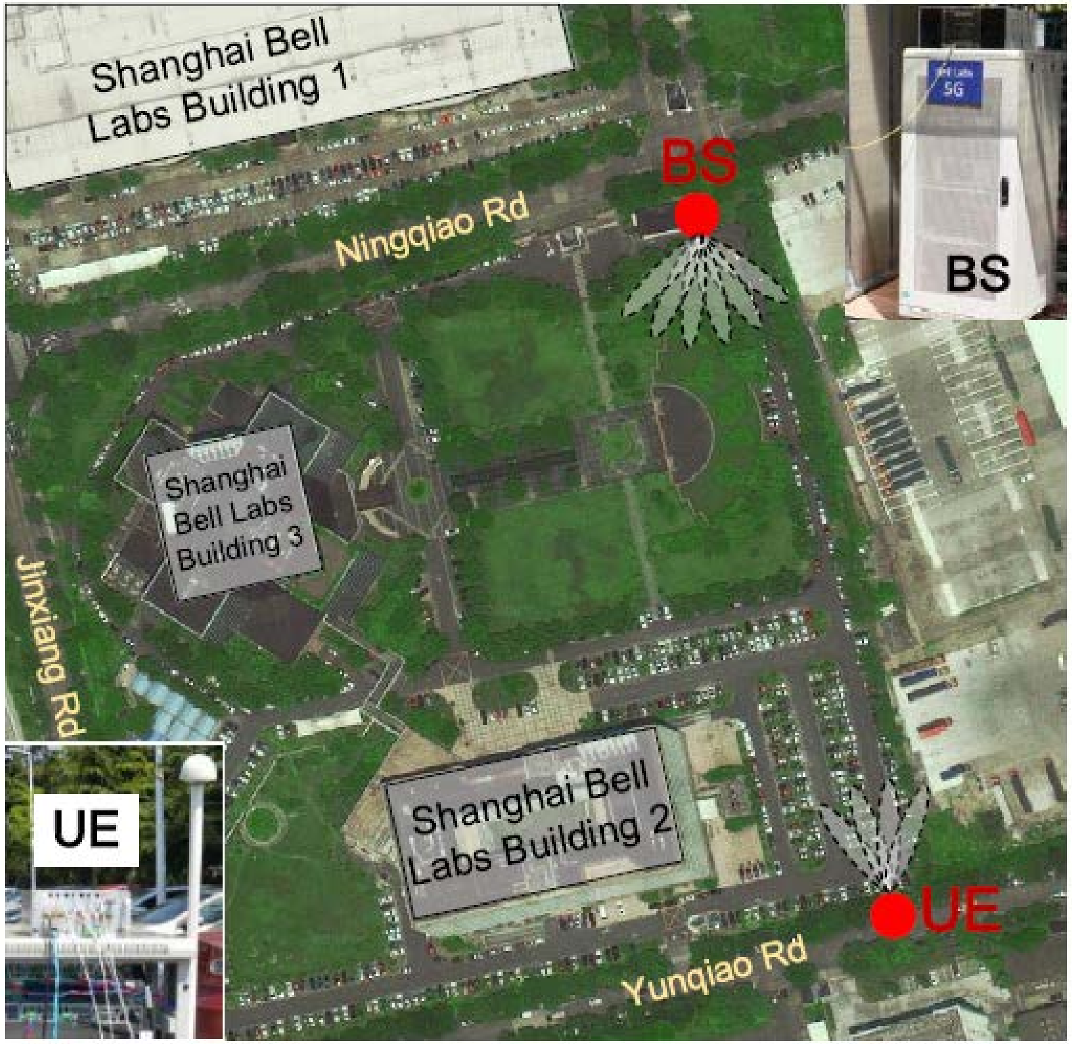
M-MIMO at mm-waves



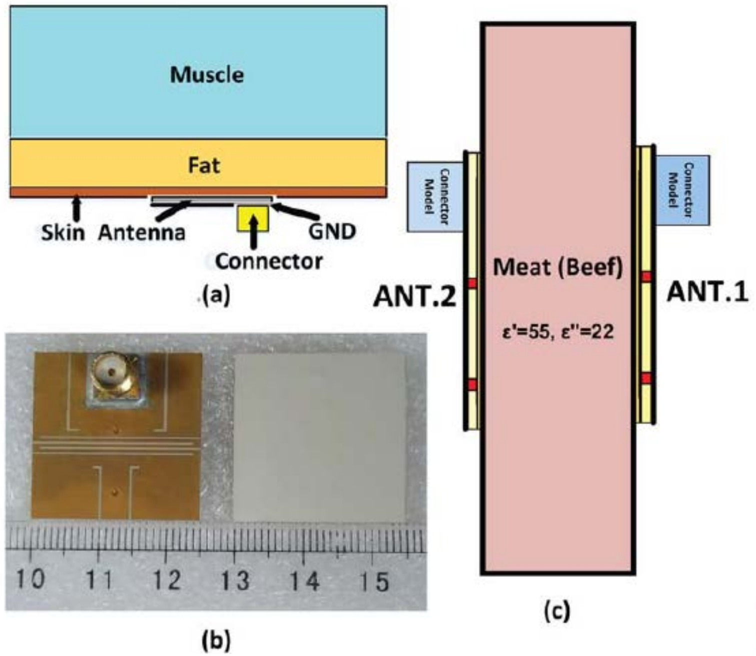
(a)

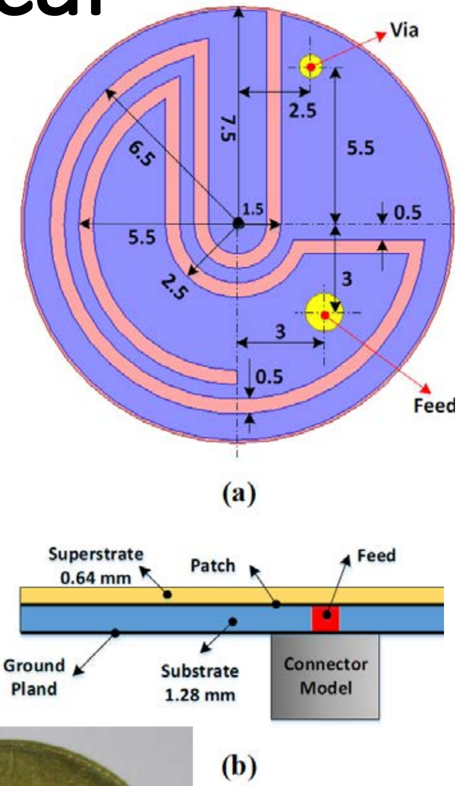
(a)

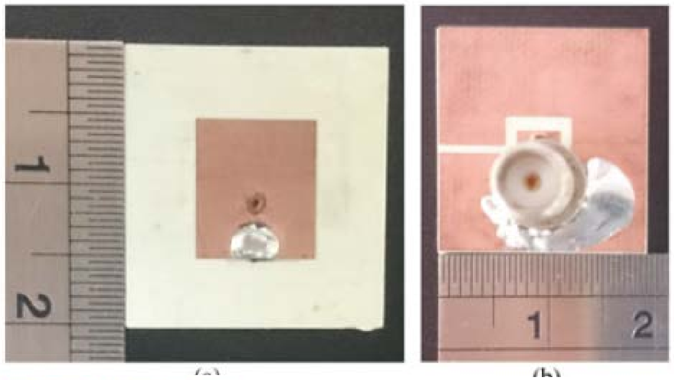
(b)

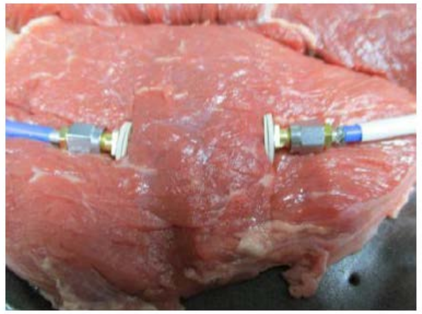

Shanghai Bell
Labs Building 1
BS
Ningqiao Rd
BS
5G
Shanghai
Bell Labs
Building 3
Jinxiang Rd
UE
Shanghai Bell
Labs Building 2
UE
Yunqiao Rd

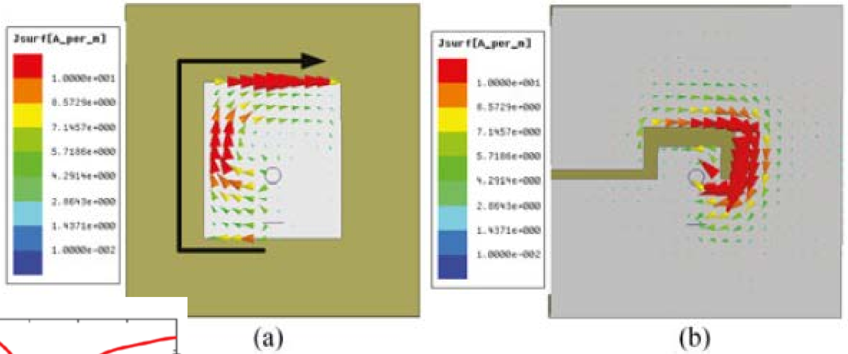
(F) Other 5G Domains:
IOT, Biomedical

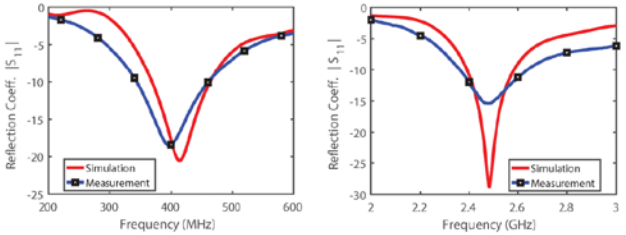

Muscle
Fat
Skin
Antenna
GND
Connector
(a)
10
11
12
13
14
15
(b)
Connector Model
Connector Model
ANT.2
Meat (Beef)
ε'=55, ε''=22
ANT.1
(c)

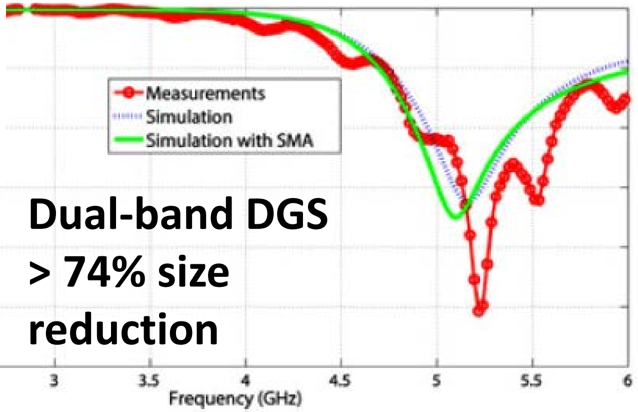

Via
2.5
7.5
6.5
5.5
1.5
0.5
5.5
2.5
3
3
0.5
Feed
(a)
Superstrate 0.64 mm
Patch
Feed
Ground Pland
Substrate 1.28 mm
Connector Model
(b)

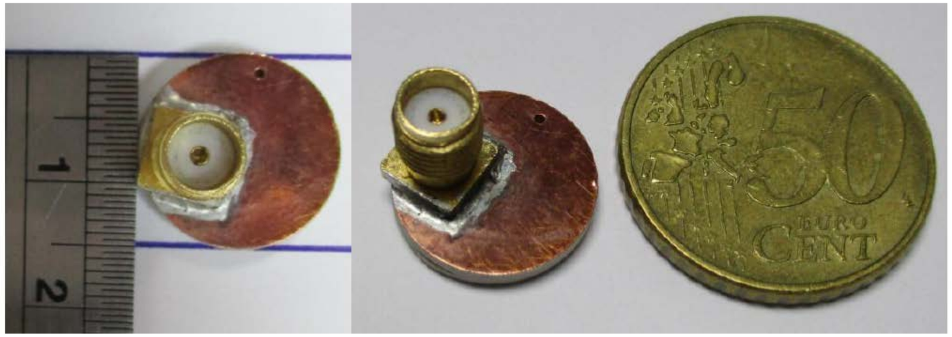





Jsurf[A_per_m]
1.0000e+001
8.5729e+000
7.1457e+000
5.7186e+000
4.2914e+000
2.8643e+000
1.4371e+000
1.0000e-002
(a)
(b)






1
2
50
EURO CENT

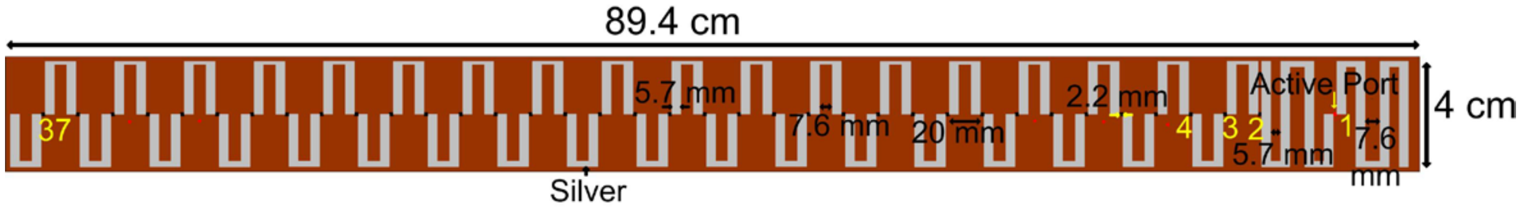
902 – 928 MHz
Superstrate loaded
More than 70% size reduction

Dual-band DGS
> 74% size reduction

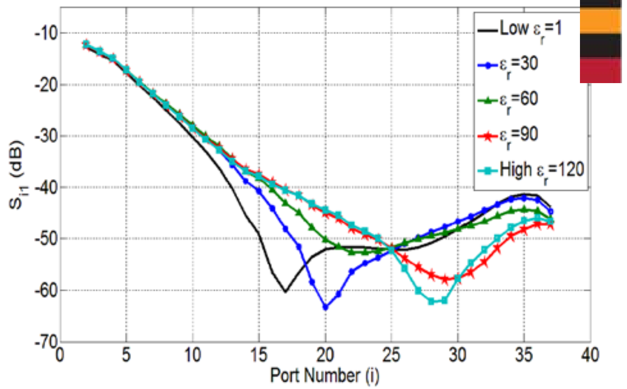
[23] A.R. Mohamed, **M. S. Sharawi** and A. Muqaibel, "Implanted Dual-Band Circular Antenna For Biomedical Applications," *Microwaves and Optical Technology Letters, Wiley,* Vol. 60, No. 5, pp. 1125-1132, May 2018

[24] A. Salih and **M. S. Sharawi**, "A Dual-Band Highly Miniaturized Patch Antenna," IEEE Antennas and Wireless Propagation Letters, Vol. 15, pp. 1783-1786, 2016.

Biomedical Sensor Arrays:


89.4 cm
37
5.7 mm
7.6 mm
20 mm
2.2 mm
Active Port
4
3
2
1
5.7 mm
7.6 mm
4 cm
Silver

Planner Design of 37-Port RF Sensor



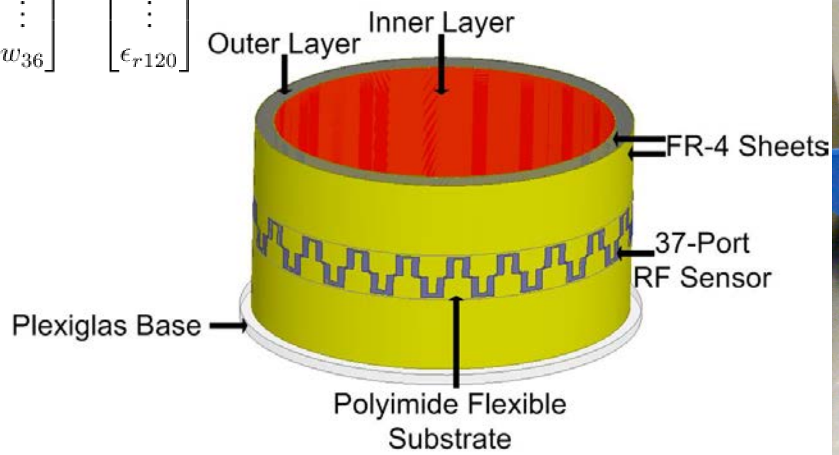
@ 60 MHz
ANP-silver ink

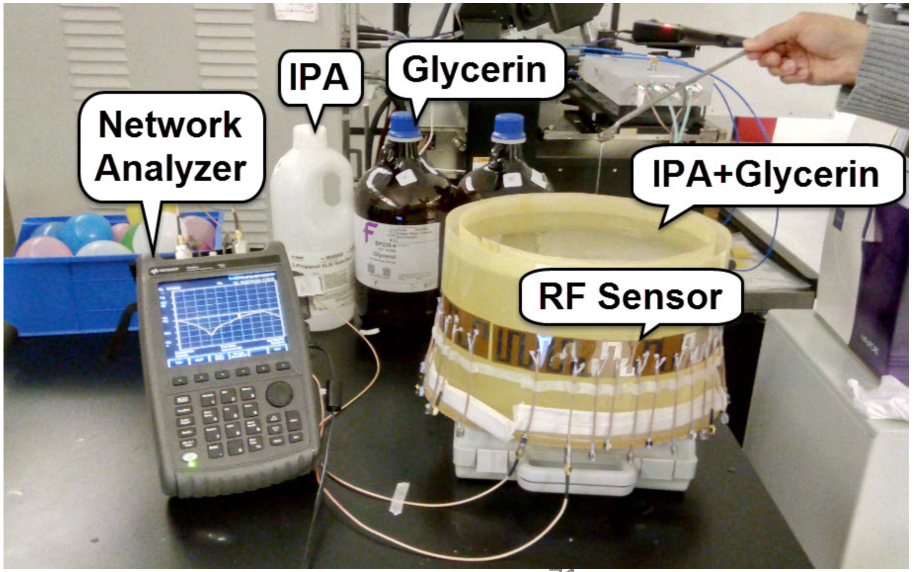
Material	Thickness (cm)	Permittivity	Loss Tangent	Conductivity
Polyimide sheet	0.005	3.4	0.01	-
FR-4 sheet	0.07874	4.8	0.017	-
Plexiglas Base	1	2.5	0.08	-
Outer Layer	1.5	40.6	2.33	0.38
Inner Layer	31.62	1-120	2-3	0.3-0.5

Category	Exact ϵ_r	Simulated ϵ_r	Measured ϵ_r	Simulated Error (%)	Measured Error (%)
Water+Salt	108	109.31	110.89	1.21	2.68
Water+Salt with 6 water balls	104	104.83	104.9	0.79	0.87
Water+Salt with 12 water balls	100	100.3	102.18	0.3	2.18
Water+Salt with 18 water balls	96	96.52	98.69	0.55	2.8

$$\begin{bmatrix} S_{2,1} & S_{3,1} & S_{4,1} & \dots & S_{37,1} \\ S_{2,1} & S_{3,1} & S_{4,1} & \dots & S_{37,1} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ S_{2,1} & S_{3,1} & S_{4,1} & \dots & S_{37,1} \end{bmatrix} \cdot \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_{36} \end{bmatrix} = \begin{bmatrix} \epsilon_{r1} \\ \epsilon_{r2} \\ \vdots \\ \epsilon_{r120} \end{bmatrix}$$

$$\epsilon_r = \sum_{i=2}^{37} w_{i-1} S_{i1}$$


Outer Layer
Inner Layer
FR-4 Sheets
37-Port
RF Sensor
Plexiglas Base
Polyimide Flexible
Substrate

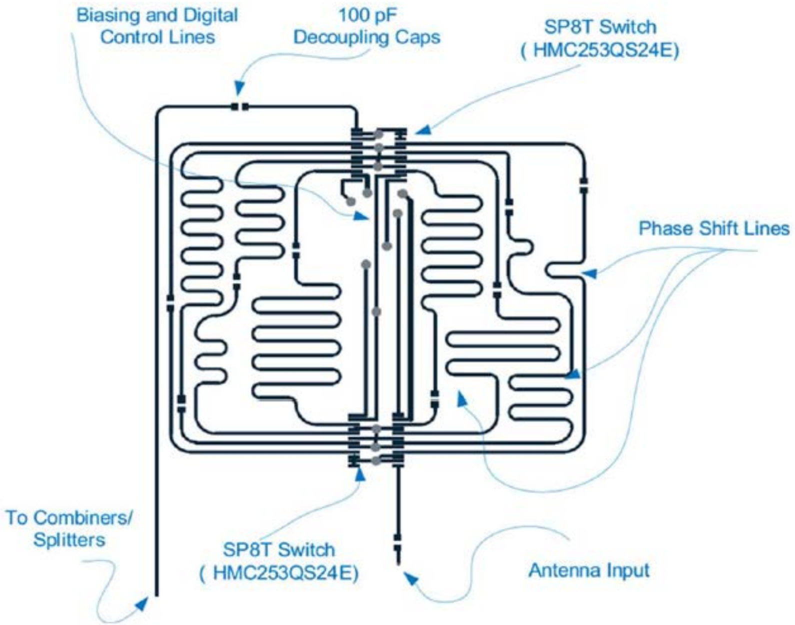

IPA
Glycerin
Network
Analyzer
IPA+Glycerin
RF Sensor

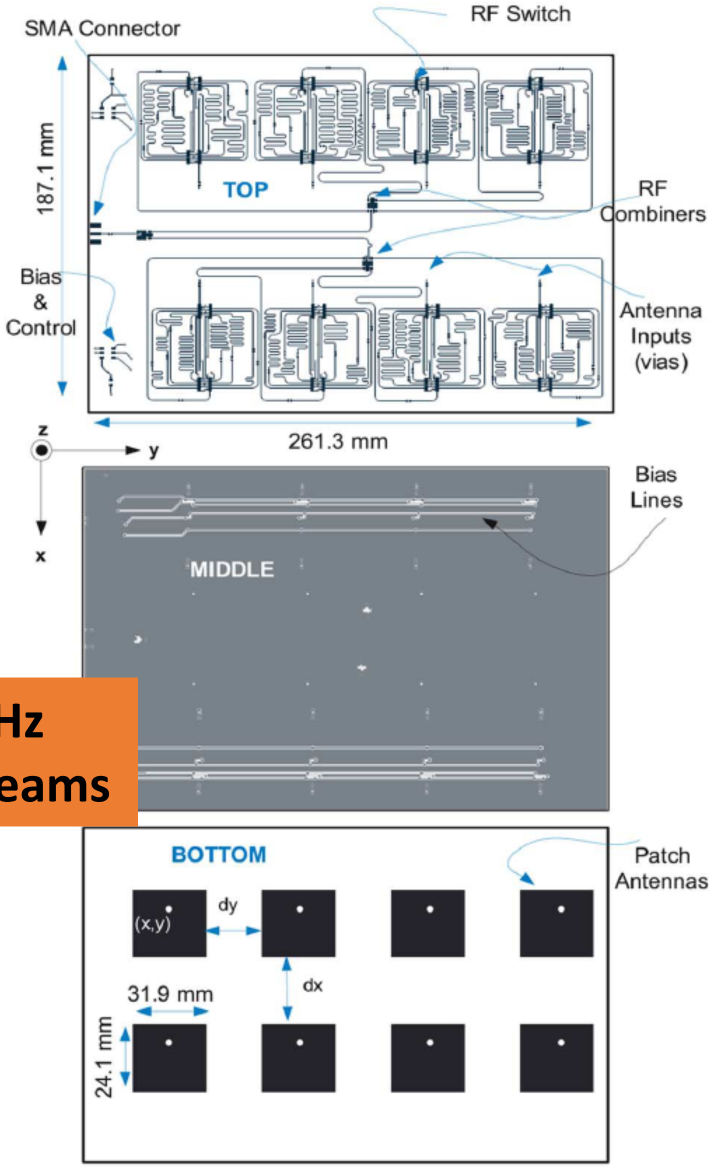
Avg. Error 2.13%

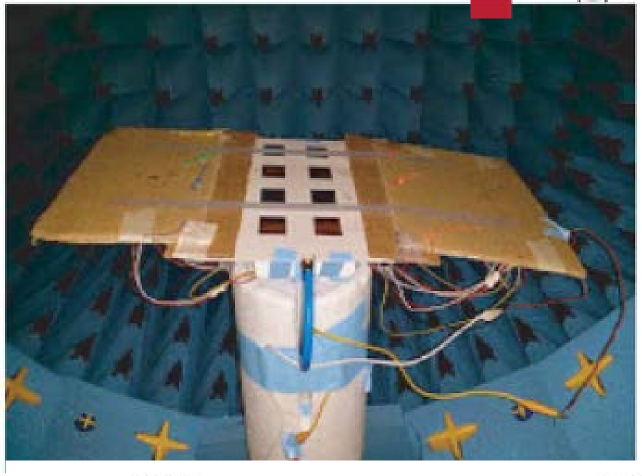
IPA: Isopropyl Alcohol

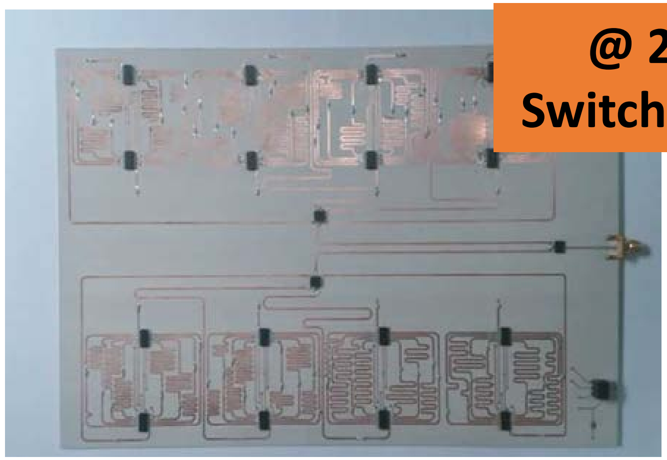
[25] M. Tayyab, **M. S. Sharawi,** A. Al-Sarkhi and A. Shamim, "A Low Complexity Radio Frequency Based Sensor Array For Lung Disease Detection Using Inkjet Printing," IET Microwaves, Antennas and Propagation, Under review.

Switched Beam Antenna Arrays (V2V):

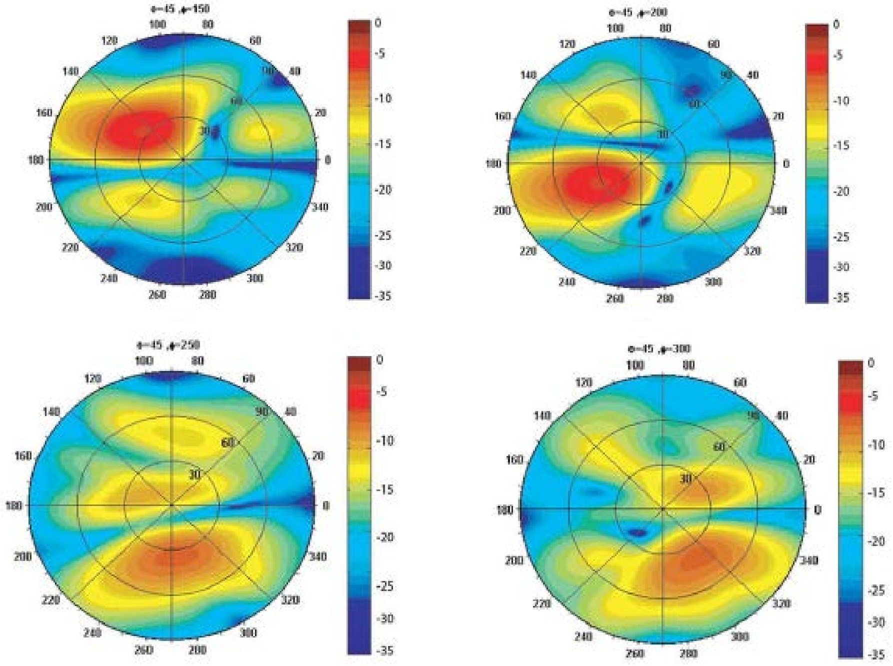

Biasing and Digital Control Lines
100 pF Decoupling Caps
SP8T Switch (HMC253QS24E)
Phase Shift Lines
To Combiners/ Splitters
SP8T Switch (HMC253QS24E)
Antenna Input


SMA Connector
RF Switch
187.1 mm
TOP
RF Combiners
Bias & Control
Antenna Inputs (vias)
261.3 mm
z
y
x
Bias Lines
MIDDLE
BOTTOM
Patch Antennas
(x,y)
dy
dx
31.9 mm
24.1 mm





@ 2.4 GHz
Switched Beams



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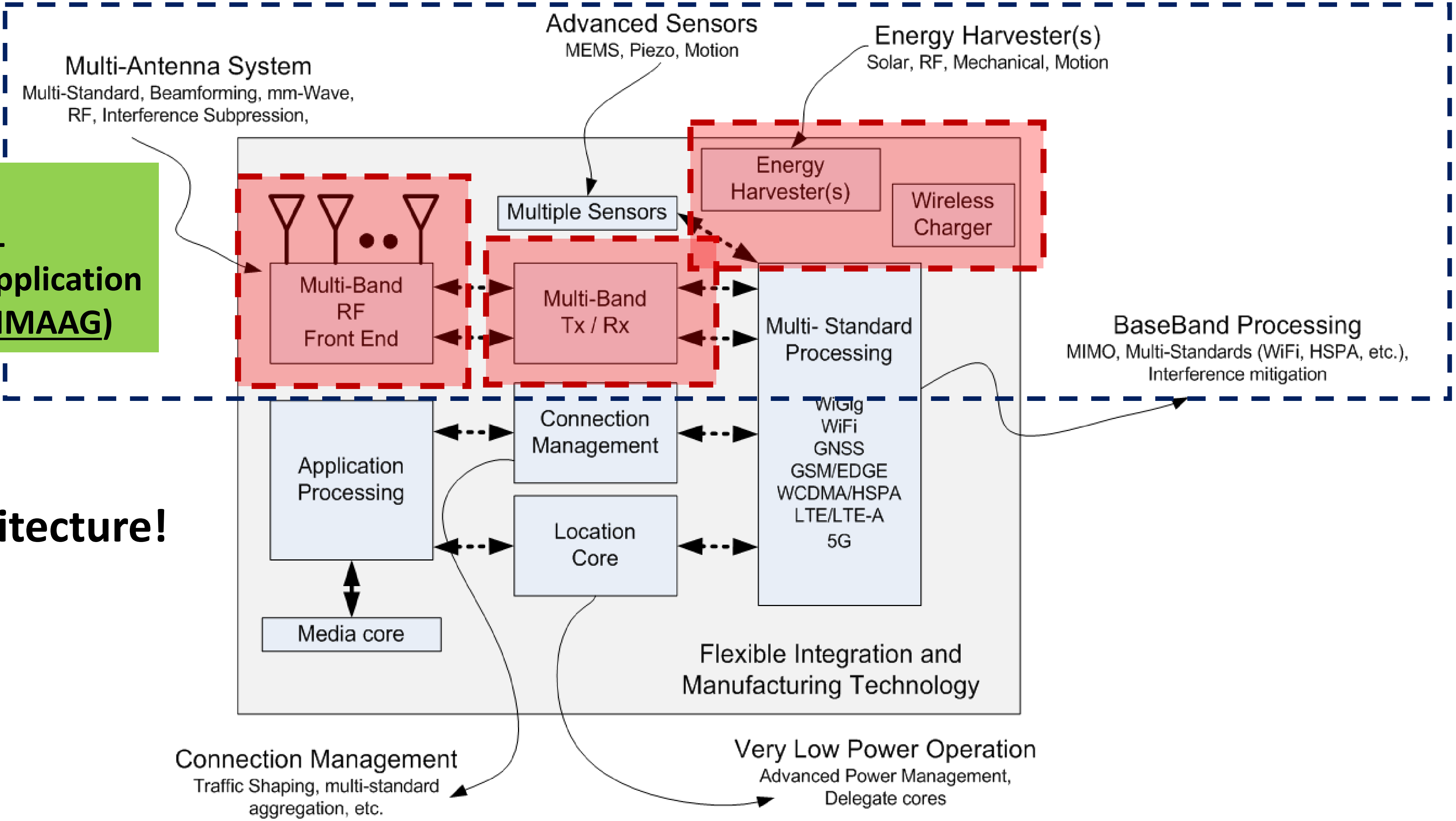
Presentation Scope

- Major Research Activities (@Polytechnique Montréal)
- Technology Trends for future Wireless Systems
- 5G technologies for Antenna Systems
  - MIMO / massive-MIMO
  - Mm-waves
- Advances in Antenna systems for 5G
  - Reconfigurable antennas for cellular and Cognitive Radio (CR) platforms
  - Active Integrated Antennas
  - Use of mm-wave antenna systems
  - CAA based integrated antennas
  - Massive-MIMO Antenna systems
  - Other 5G applications
- Future Challenges

Future Challenges in Handset Antenna Designs

Focus of
POLY-MTL
Integrated Multi-Application Antenna Group (IMAAG)

5G radio architecture!



Multi-Antenna System
Multi-Standard, Beamforming, mm-Wave, RF, Interference Subpression,

Advanced Sensors
MEMS, Piezo, Motion

Energy Harvester(s)
Solar, RF, Mechanical, Motion

Multi-Band RF Front End

Multiple Sensors

Energy Harvester(s)

Wireless Charger

Multi-Band Tx / Rx

Multi- Standard Processing
WiGig
WiFi
GNSS
GSM/EDGE
WCDMA/HSPA
LTE/LTE-A
5G

BaseBand Processing
MIMO, Multi-Standards (WiFi, HSPA, etc.), Interference mitigation

Application Processing

Connection Management

Location Core

Media core

Flexible Integration and Manufacturing Technology

Connection Management
Traffic Shaping, multi-standard aggregation, etc.

Very Low Power Operation
Advanced Power Management, Delegate cores

Potential challenges (Personal views 101)

- Active integration and coming up with miniaturized active Antenna + FE modules
- On-chip/On-package/in-package antenna array solutions
- Beamforming (or beam-switching) capabilities @mm-waves
- Proper Testing and characterization (on-package arrays, embedded antenna solutions, surrounding effects (hands, head, cover, etc.), etc.)
- CAD design and simulation times, need enhancement in modeling tools
- Health issues? Further investigation and coming up with new limits
- Beyond 5G solutions…. Open the door to 6G beyond 100GHz for short data links

→ Towards ultimate integration between antennas, electronics and algorithms!

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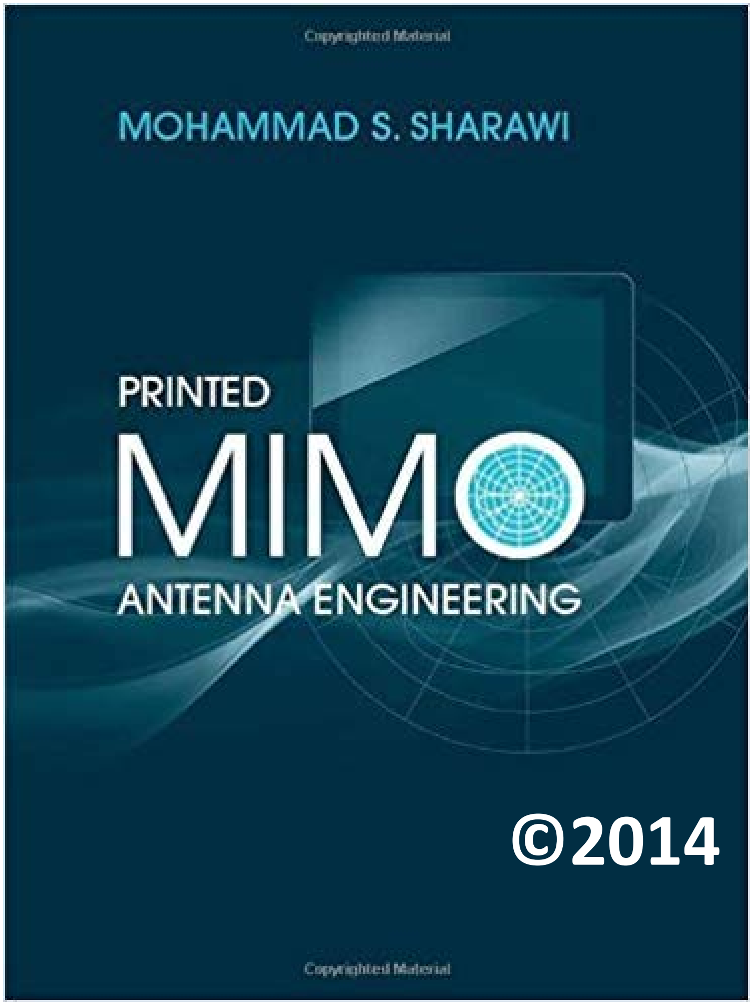

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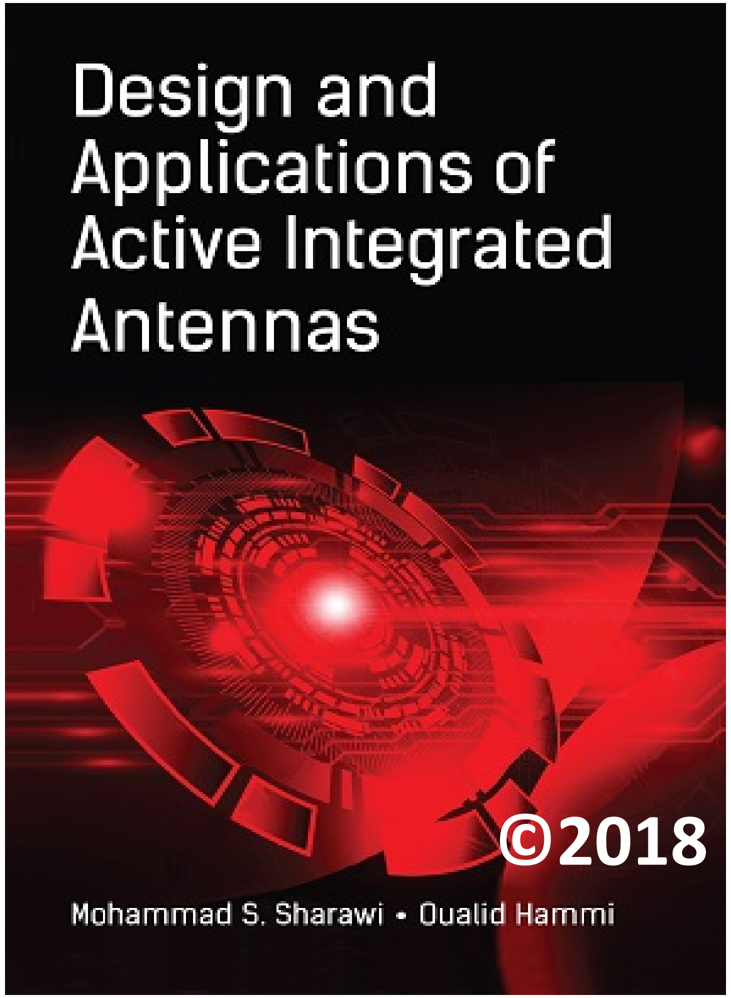

Design and Applications of Active Integrated Antennas

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Mohammad S. Sharawi • Oualid Hammi

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THANK YOU
FOR LISTENING

Questions?

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